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GEOLOGY

OF THE

CAPE COD DISTRICT

BY

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INTRODUCTORY NOTE.

It was at first intended that this paper should include the geology of the peninsula of Cape Cod only, but the progress of the work has made it necessary to extend the consideration so as to take some account of the structure and the succession of deposits exhibited in portions of the mainland, as well as on the islands to the southward. The progress of the inquiry has made it necessary to limit the scope of the work to a somewhat extended discussion of the evidence that goes to show the series of geological events which have occurred in this district since the beginning of the Cretaceous period. Such of the facts as pertain to this discussion are given in this paper; further details will be set forth in the geological folios of the area, which it is expected will shortly be ready for the press.[1]

Inquiries in this field have been very limited in their number and range. Those instituted by the United States Geological Survey have resulted in a Report on the Geology of Marthas Vineyard, in the Seventh Annual Report of the Director (for 1885–86); a report on The Geology of Nantucket, being Bulletin No. 53 (1889) of the Survey series (both by the writer of this paper); a report on The Glacial Brick Clays of Rhode Island and southeastern Massachusetts, by N. S. Shaler, J. B. Woodworth, and C. F. Marbut, in Part I of the Seventeenth Annual Report of the Survey (for 1895–96); and the unpublished folios above referred to.

The reader of the above-named published reports and of this paper will perceive that the Cape Cod district has unexpectedly revealed a considerable range of phenomena, the discussion of which is certain to throw much light on the geological history of the Atlantic coast line. Unfortunately the evidence concerning the succession of these phenomena is of a very obscure nature, and it is therefore not surprising that in the reports above referred to some of it was misapprehended and much was not discerned. Nor must it be supposed that in the following pages anything like a final statement of the facts or of the conclusions to be drawn from them is to be found. Such a statement can not be expected until investigation has gone much further.

I take pleasure in acknowledging indebtedness to Mr. J. B. Woodworth for advice in some parts of the work, and to Messrs. Mark S. W. Jefferson and John Gardner for help in obtaining the photographs from which the illustrations are taken.

[1] Folios of the Geologic Atlas of the United States.

ORIGIN OF CAPE COD PENINSULA.

The origin and structure of the peninsula of Cape Cod have been a matter of passing interest to all who have considered the geology of the southeastern portion of New England. The peculiar spit-like form of this promontory was at first, and naturally, supposed to be accounted for by the action of the marine currents to which are due the construction of so many of the lesser capes along this portion of the Atlantic shore. When it became evident that a large portion of the materials composing the higher parts of the cape had been brought into position by the action of ice during the last Glacial period, the spit theory was abandoned, and it was at once assumed that the greater part of this area owed its existence as dry land to the morainal and stratified drift deposits which are so evident on the surface, the northeastern extremity being a later addition, made by the action of marine waves and currents.

The last-noted hypothesis as to the origin of Cape Cod, by glacial action, long appeared to have much support from the view, so generally entertained, that the outer morainal deposits formed during the advance of the ice were likely to be massive and of great extent; so that it thus seemed reasonable to suppose that the portion of this cape that was evidently not due to marine agencies was accumulated as a frontal moraine. An inspection of this field alone, without the use of corrections which may be obtained from other parts of the country, almost necessarily leads the observer to adopt the view last mentioned. It was not until I had seen much of the morainal deposits of the region between the Cordilleras and the Atlantic shore, and had made a study of the relations of those accumulations to the Tertiary and Cretaceous rocks of Marthas Vineyard, Nantucket, and other parts of the Atlantic coast line between southern New Jersey and Boston Bay, that I gained what seemed to me to be a truer insight into the nature of the singular peninsula of Cape Cod. On this account it appears desirable to preface the study of this district by an account of the facts revealed in neighboring fields which seem to throw light on its problems.

GENERAL RELATIONS OF THE DISTRICT.

A glance at a map of the eastern shore of North America will show that the peninsula of Cape Cod is in some respects the most peculiar feature of this coast line; geographically considered, it is in a high measure exceptional. Its crescentic form, as before remarked, is by no means unique, except as to the great size of the hook, many of the sand spits imitating in a small way the general coastal outline of this peninsula; but in the bold manner in which this salient projects from the shore, in its strong topographical relief, and in the character of its coast line, it finds no parallel, so far as I have been able to ascertain, in any country. This exceptional geographical character naturally leads an observer who is aware of the indicative value of such features to

seek the origin of this cape in conditions of an unusual sort, such as will become apparent in a discussion of the general relations of the district.

It has long been known that the Cretaceous and Tertiary deposits so extensively developed in the southern portion of the Atlantic States of this country are continued in an interrupted belt lying to the east of the more ancient rocks as far north as southeastern Massachusetts, the Cretaceous extending up to the deposits on Marthas Vineyard and the Miocene Tertiary reaching to Marshfield, a point some distance north of the northern border of Cape Cod. Associated with these Mesozoic and Cenozoic deposits are extensive series of stratified sands and gravels which have hitherto been commonly classified with the glacial drift. South of New York these beds show little signs of disturbance by orogenic action; such distortions as have been noticed in the beds can apparently in most cases be explained by accidents of deposition. North of New York, on Long Island and in the isles to the eastward, these beds have been subjected to dislocation, which in Marthas Vineyard becomes profound, so far as is indicated by the attitude of the beds, exceeding on the average the distortions of the Appalachian Mountain district or of the neighboring field of the Narragansett Basin.

Certain observers have sought to account for the dislocations of these newer rocks on the New England shore district by supposing them to be due to the action of the glaciers of the last ice epoch. As I have elsewhere noted, this view seems quite inadmissible, for the reason that the uplifting and folding of the beds took place long before the advent of the last ice epoch. As this point is of much importance in the discussion of the problem as to the origin of Cape Cod, it will be well to present the facts in some detail, especially as certain excavations recently made on Marthas Vineyard have somewhat extended our knowledge concerning the history of the glacial work in that field.

On Marthas Vineyard the Cretaceous and Tertiary strata, exhibiting a total section of probably 1,000 feet or more, are cast into folds of considerable amplitude, some of them apparently exceeding 1,500 feet in transverse extent. These folds are compressed, overturned, and faulted; in a word, they exhibit all the marks of mountain-building actions working on stratified deposits of weak resistance to compression and not deeply buried. So general and effective has this dislocation been that it has involved all the rocks which are exposed to view, the average dip of the strata perhaps exceeding 40 degrees.

In these exceedingly disturbed strata river valleys were excavated which had their position determined in the usual manner, the greater streams following in general the strike of the beds, the lesser—those occupied by the temporary streams—running at right angles thereto. The larger of these valleys, that of Tisbury River, is about one-third of a mile wide and more than 100 feet deep. Upon this normal and well-developed topography, which indicates a continuance of stream erosion that must have occupied a period to be measured by tens of

thousands of years, came the glacier of the last ice epoch. I have elsewhere[1] noted the fact that this ice sheet had little erosional effect upon the topography of this island, and the impression made by my first studies has been confirmed by recent inquiries in the same field. The facts may be briefly stated as follows:

The ice sheet failed to obliterate many details of the topography which were due to differential erosion before the advent of the glacier. At many points the ridges of harder rock, though at most no firmer than compacted sand or soft clay, stand evidently as they were originally formed. So imperfectly did the ice abrade the surface that the white and red colors of the clays is rarely traceable to a height of a foot above the contact of the till with the underlying beds. Although along the crests of the greater ridges there are morainal accumulations which have in places a thickness of from 20 to 50 feet, these are limited to the northern side of the island; the southern part has only slight moraines. Over nearly one-half the area in which the Cretaceous and Tertiary strata rise above the level of the sea the till coating does not average 3 feet in thickness, and many fields of a hundred acres or more in extent are essentially driftless. On the southern shore the evidence at present afforded by the rapidly retreating cliffs is to the effect that a deeply incised topography formed in the Nashaquitsa clays was not effaced, the sharp valleys being merely filled in with the drift deposits. In a word, the conditions of this area indicate that the glacier of the last ice epoch was of such slight dynamic value that it produced little erosion and that all the important dislocatory work was done long before it came upon the district.

It is to be said that there is some evidence of ice action shown by the character of the latest-formed deposits of the disturbed strata, seen in the presence in one of the conglomerates exhibited at Gay Head of pebbles and bowlders apparently derived from the region of Narragansett Bay, including one fragment of the very characteristic ilmenite from Iron Hill, in the town of Cumberland, Rhode Island. But this ice period of the Pliocene or Pleistocene time was, if it existed, so far as we can discern, an even less effective invasion than that of the last Glacial epoch, and, as it came before the dislocation of the beds, can not possibly be made to account for their disturbance. There is thus no reason to doubt that the extensive stress phenomena of this field must be explained by supposing that they are in some way the result of orogenic action. We are, indeed, justified in assuming that along the section of the shore line extending, it may be, from western Long Island to the island of Nantucket, mountain-building movements involving stresses of considerable intensity have been developed.

As to the operation of these mountain-building actions in the district of Cape Cod, the evidence, though not perfectly clear, leads to the

[1] Report on the geology of Marthas Vineyard; Seventh Ann. Rept. U. S. Geol. Survey, 1885-86 (1888), p. 310.

conclusion that they worked on the ill-disclosed foundations of that peninsula in much the same manner that they have done in the well-exhibited beds of Marthas Vineyard. As will be noted in the sequel, the strata which are known on Cape Cod include nothing below the level of the Nashaquitsa series as described in the report on Marthas Vineyard; but the presence of the Tertiary greensands at Marshfield causes the presumption that beds of earlier age lie within the peninsula.

The limited extent of the exposures of the foundation materials of Cape Cod makes it desirable to take into account the structure and history of the adjacent areas both on the south and on the north. It is, indeed, necessary to do this in order to arrive at an understanding as to the history of the particular area. This consideration should include the origin of the sediments, the nature of the transporting agents which brought them to their sites, the orogenic accidents, the development of the drainage, and the oscillations of the sea level which have taken place on this portion of the shore.

The sediments of the Cretaceous and Tertiary rocks in the district between Washington and Boston exhibit certain peculiarities which are not found elsewhere in the eastern United States. The section is in part made up of colored clays and sands, which, except for the admixture of peaty matter in the lignite beds, are evidently derived from the rapid deposition of land waste washed from an area which had been long subjected to interstitial decay, which was followed by rapid erosion. In the lower portion of the beds the conditions are not so abnormal, the clays and sands in general resembling those of the Southern States. They appear to have been deposited from the discharge into the sea of ordinary rivers. The structure of the lignites, which, so far as observed, contain much clay, indicates that they were formed in an estuarine district, subjected to frequent floodings of muddy water and to slight subsidences, which permitted the peaty accumulations to be buried beneath silt.

In passing to the higher marine strata, we find at once that we are in very different clastic conditions. The beds in the Marthas Vineyard district consist of alternating clays and sands, which have evidently been deposited in a rapid manner. The clays show scarcely a trace of lamination, and the sands are exceedingly coarse, often being made up of bits of decayed granite, the crystals running together in one mass. Much of the deposit is composed of detached, not rounded, crystals of feldspar, which are so far softened by decay that they can be crushed in the fingers. It is, in a word, a true arkose, lacking only the usual consolidation of that material, and so destitute of admixture of such substances as are inevitably brought into detrital beds where the transportation which bore the waste to its resting place was by rivers or shore currents, that a careful study of sections many square yards in area has failed to show a trace of any other material than the broken-up crystalline rock from which it was derived.

After passing up through a section having a total thickness of several hundred feet in which the above-noted alternations are exhibited, we come suddenly to a level where beds of conglomerate, composed of ordinary compound hypogene rocks, occur in pebbles of moderate size not differing much in character from those formed during the last Glacial period, except that they are more decayed and somewhat more waterworn. Yet higher in the section we attain to the Nashaquitsa series, which are also somewhat dislocated. These are beds of sands and clays, in general character like those formed during the last Glacial period, though on account of their greater age they have been much more changed in texture than those of that epoch. The interpretation of this section is difficult. The most probable explanation is that which will now be set forth.

In the first place, we may note the fact that the shore line of the old crystalline district of the Appalachians appears always to have lain near this seat of deposition. The arkose in the Tertiary shows this to have been the case in that period. It was so again at the time of the higher conglomerate, and the character of the clays and arkose beds shows that they were not offshore deposits. The structure of these beds suggests that they were laid down in a swiftly accumulated delta at the mouth of a river, which might well have been a continuation of the Connecticut.

The lower Cretaceous deposits, being in nature such as would be discharged from streams draining a land subjected to ordinary conditions of erosion, demand no special explanation. As before noted, it is quite evident that the rocks beneath the land from which they came had been deeply decayed in a long period of stable conditions, such as has prevailed in the southern Appalachians. Suddenly this zone of decay was to a great extent swept away into the neighboring sea, the process continuing until, as the conglomerates which cap the Tertiary section show, the firm-set undecayed rocks were, in certain places at least, exposed to the eroding agents.

The supposition that there was in the Mesozoic period a deep zone of decayed rock in New England which might have afforded, if subjected to rapid erosion, detritus such as is contained in the clays and arkoses of the Tertiary rocks of southeastern Massachusetts, finds some support in the occurrence at many points in that area, particularly in the southern half thereof, of rocks decayed in place under conditions which clearly show that the disintegration has not been brought about since the last Glacial period. Rocks in this state, exhibiting decay to the depth of some score of feet, occur at various points in and about the Boston Basin, and in a number of places in the Berkshire Hills and elsewhere. A notable instance of this decay of the strata in place was found in the excavation of the Hoosac Tunnel, where, for a length of several hundred feet, near the western portal, the mica-schist was found completely softened at a depth of 400 feet below the surface. Owing

to the deep covering of glacial drift which hides so much of the surface of New England, as well as to the fact that the ice of the last ice period removed all projecting rocks of this nature, it is only chance excavations, such as are rarely made, that give one an opportunity to see these remnants of a decay which was once widespread. From a careful examination of the evidence, I am of the opinion that at least one-thirtieth part of the crystalline rocks of Massachusetts, Connecticut, and Rhode Island would, if bared, exhibit decay of the type so well known in the plateau district of the southern Appalachians.

The cause of the sudden removal of this material from its old to its new bed place is not easily determined; the following suggestions seem, however, worth consideration. It is doubtful that the result was brought about by the invasion of the sea during a period of subsidence; the singularly unmixed character of the deposits, the entire absence of marine organic waste, which is likely to be found in beds of this nature, and the perfect assortment into thick layers of like sediments are also against this view. Moreover, the cutting rate of coastal erosion agents is normally slow, while these beds indicate very rapid work of this kind. So, too, the hypothesis of exaggerated land erosion due either to a great increase in rainfall or to a steepening of valleys brought about by a change in the attitude of the land, seems inadmissible for the reason that the detritus from any ordinarily conditioned area would have been stained by the organic waste that all such streams normally bear to the sea. It is difficult to conceive a large river carrying and depositing in succession red and white clays and arkoses without a trace of vegetable detritus.

The difficulty which is encountered in the effort to explain the erosion of the detritus of the Gay Head beds by marine action is well illustrated by what is now taking place on the rapidly wasting cliffs of that part of Marthas Vineyard. The materials of the section are to a certain extent rearranged along the shallow-water belt of the shore, but the various forms of detritus are intermingled, and are mixed with organic matter to such an extent as to make the intervention of the sea unmistakably manifest.

It may be suggested that the beds in question have in some way been bleached or colored since they were deposited. This view can not, as is at once seen, be maintained in the case of the clays, for the lignite beds of the Cretaceous which are mingled with them carry the carbonaceous stain with no trace of bleaching. I have been unable to conceive any chemical action occurring in either the clays or the arkoses which might possibly account for the disappearance of original organic waste.

In this state of the problem I have been forced to bring in the hypothesis that the erosion work which removed the materials of these strata from their parent rocks was effected by glaciation, the ice not attaining to the place of deposition, but delivering the detritus to

streams, one or more of which debouched near this part of the coast into the sea, or perhaps at times into a lake. Glacial action accounts for all the facts which we have noted concerning the character of these deposits in a way that no other operation could well do; in fact, without using this hypothesis we are left quite without an explanation of a very interesting series of phenomena.

In favor of the hypothesis that glacial erosion delivered the detritus of the Cretaceous section to the currents which bore it to its present resting place, we may note the fact that occasionally, though rarely, in the clays of the Gay Head cliffs we find large, subangular masses of a yellowish-red sandstone embedded in the strata. One of these, visible for some years, has recently fallen and broken to fragments. It was originally not less than 20 cubic feet in volume. In the course of the thirty-six years that this slowly retreating cliff has been under my observation, five or six of these interesting fragments have been noted which were certainly not to be classed with the ordinary glacial bowlders that often work down the slopes so as to appear as if they were embedded in the strata. It will be observed that these apparently ice-rafted rocks are of sandstone, a material which sometimes resists the process of decay where all ordinary hypogene rocks yield to it. It is just such a petrographical species as we should expect to find affording the rare bowlder which would be formed where glaciation took effect on an area indicated by much decayed crystalline rocks. Thus in the Connecticut Valley, whence these floated masses possibly came, borne by ice rafts, the sandstones have suffered but little interstitial decay, while the older rocks of the neighboring Berkshire Hills have, as noted, been in places much disintegrated.

The orogenic history of the Cretaceous and Tertiary strata of the New England islands is even more puzzling than are the conditions of their formation. So far, no evidence has been adduced to show the action of mountain-building forces in any of the beds of this age in the region south of New York. To find on this portion of the coast much evidence of dislocation of a high order is surprising; it justifies, indeed, the effort of those geologists who have endeavored to account for these movements by the thrusting of the ice sheet. We have seen that this explanation is for several reasons inadmissible, and the question arises as to the origin of the compressive strains which have acted in this area. To determine this, so far as it is at present determinable, we should begin by noting the following facts:

The amount of the shortening of the beds as shown on Marthas Vineyard, where a cross section having a length of about 5 miles is exposed, is probably nearly 2 miles. This is shown by the fact that the average dip of the beds, as determined by many observations, is about 45 degrees. There is good reason to believe that the area involved in these disturbances is much greater than the exposures on the island seem to indicate. In my opinion the beds may reasonably be supposed

to have at least twice the extension across the strike that is known to exist, and it is not improbable that the area involved may have a width of 30 miles. The dislocations on Nantucket, though not well known, and those noted by Mr. Woodworth on Block Island, and also those on Cape Cod, hereafter to be described, seem in a way to validate this conjecture.

We have next to note that while the strikes of the folds on Marthas Vineyard are somewhat irregular, their commonest direction is from north-northwest to south-southeast, or nearly at right angles to those of the Appalachian folds of the neighboring mainland. This feature at first raised a doubt as to the orogenic nature of these foldings, for the reason that it seemed unlikely that such a departure from the normal strike of the district would take place if the movements were in character like those ordinarily involved in mountain building. But a comparison of the facts with those observed in other areas makes it clear that this discrepancy is not of great significance. In the Cordilleras and elsewhere it is not uncommon to find that the later movements in any mountain system show the effect of stresses acting at high angles, or even normal, to those which were originally effective. It seems, indeed, that the compressive strains of any district tend in the course of time to satisfy themselves through folds running in more than one direction; that when the strains in a certain axis are relieved there is often a tendency to form others in contrasted directions rather than to develop those which were first made. Therefore, the peculiar position of the axes of Tertiary disruption in this area can not be urged as a weighty argument against their true orogenic character.

It is to be observed that the dislocations of the Marthas Vineyard and Cape Cod sections differ in a notable way from those which occur in the older rocks of the Appalachian district. The folds are small, none of them, so far as clearly observed, exceeding a few hundred feet in horizontal amplitude; they are much compressed, and frequently overturned; they are cut by numerous faults, none of which appear to have a throw of more than 100 feet. In some places these accidents of stressing are so numerous and have so intermingled their effects that the result is a confused jumble of entangled beds which can not well be unraveled. At first sight these peculiarities of movements of the Marthas Vineyard section suggest to anyone familiar with ordinary mountain-building work that the strains which have effected them were of a different order from those which uplifted the Alleghenies and other normally folded mountains. It is, however, to be noted that the stresses which acted on these newer rocks took effect under very different conditions from those under which the old strata of the Appalachians were dislocated. There the beds were rigid and deeply buried; here they were soft and had little overburden to oppose their movements when the stress was applied to them.

As yet we have little information concerning the nature of the work

done by orogenic action in the superficial portions of a section on which it has taken effect, but all the considerations derived from laboratory experiments, as well as from the principles of dynamic action, lead us to believe that near the surface of a stressed area the folds are more likely to be small and of varied form than in the deeper-lying parts of it, and that in soft strata without beds of such rigidity as to control the movements slight local accidents are likely to determine the formation of many small folds rather than a few of large size.

It is worth while here to note that these Vineyard dislocations, in case they are accepted as of truly orogenic nature, may well be taken as examples of what is likely to be the type of mountain folding as exhibited in weak beds which, at the time of disturbance, lie within a few hundred feet of the surface. So far as I am aware, there is no better place known in which to study this interesting phase of mountain building.

Assuming, then, that the rocks of the sections exhibited on Marthas Vineyard owe their very great dislocation to forces which had their origin in the under earth, I shall consider certain possibilities as to the exact source of these strains. It may be suggested that a slipping movement has occurred in these beds, due to the formation of a great inclined fault extending parallel to the shore and dipping toward the sea at a high angle, the resulting movement being in effect a landslide. This view is inadmissible for the reasons that there is no trace of such a slip fault; that the section moved is of a rank in size of which we have no knowledge elsewhere; that the transverse shortening of the beds is too great to be accounted for in this manner, and that the direction of the axes of the folds is at about right angles to such as would be formed in such a movement.

It may be worth while to set forth another hypothesis which I have been led to apply to these movements in order to arrive at an explanation of them without recourse to true mountain-building action. This is as follows: A large part of the materials in the Marthas Vineyard section is feldspar, which had apparently been imperfectly kaolinized before it was brought to its present site. Is it not possible that the considerable increase of bulk attendant on this conversion of feldspathic matter into kaolin may have led to internal pressures? It appears, however, that of the mass not over 15 per cent can be reckoned as feldspathic, while even if the whole of it were of that nature and all the changes had come about since the beds were laid down the amount of enlargement would be too small to account for the observed disruption of the beds.

It seems evident that we must account for the folding and other movements of the Tertiary and Cretaceous rocks of these New England islands by the ordinary process of mountain building. Questions then arise concerning the nature of the dislocations by which the compressive strains were applied to these superficial beds. The general slope of the hypogene and Carboniferous rocks on the neighboring

mainland makes it eminently probable that these old deposits underlie the newer beds at a depth of not more than 1,000 or 2,000 feet below the surface of the sea. How, then, were these lower beds affected in order that they might transmit the strain to the Mesozoic and Cenozoic deposits? and what, if any, were the dislocations on the mainland that were produced at the same time? It seems to me that neither of these questions is, in the present state of the inquiry, answerable with any measure of affirmation, but some suggestions may be made which are perhaps not without value.

As to the movements of the rocks, presumably crystalline, that constitute the foundation of the Marthas Vineyard section, the conditions are substantially the same as those which have existed beneath the Carboniferous deposits of the Narragansett Basin. When they came to be folded, with a measure of compression quite like that which has affected the beds with which we are now concerned, as we may see when the folded Carboniferous beds have been stripped away from the hypogene rocks, the yielding of the crystallines appears to have been made mainly by the interstitial movements of those rocks, and not to any great extent by faulting. All the evidence we have goes to show that while ordinarily massive crystalline rocks may be folded, as is sometimes indicated by the dikes they contain, a frequent method of accommodating themselves to pressure is by squeezing. This action is, indeed, common enough in all rocks which have been subjected to compression strains, as is shown in the distortion of fossils. The absence of any distinct indication of recent faulting on the mainland near Marthas Vineyard affords some support to the supposition that the giving way of these basement rocks was rather more by interstitial movement than by dislocation.

It should also be said that the peculiar position of the masses of decayed crystalline rocks which, as above noted, occur in the three more southern States of New England, long ago led me to the supposition that, after this decay had been effected, a certain amount of faulting occurred, which lowered wedges of the disintegrated rock down to levels to which the surface actions had not penetrated. Moreover, efforts which I have made to account for the details of the topography at several points in southern New England have led me, quite independent of the problems of the Tertiary dislocations, to the idea that at a time not long before the last Glacial epoch there was a certain amount of disruption by faulting in that part of the mainland. This problem of recent faulting on the mainland needs more study than I have been able to give to it; the matter is only suggested here to show that there may be more extensive evidence of orogenic action on this part of the continent than has hitherto been supposed.

A part of the difficulty connected with the question as to the nature of the movements involved in the dislocation of the Marthas Vineyard section arises from the fact that the development of these folds and

faults has apparently taken place in a basin without a border of harder rocks on either side through which the compression strains might have been carried. It seems likely that the contraction of the basement beds, however great, would have failed effectively to compress a thick mantle of soft material unless it had been in a basin. The natural result, if the beds lay on a sloping floor without a rim, would appear to be a mere slipping of the bed rocks upon the softer materials, without any such folding as we find. There are obviously no marks of a basin structure made up of the older rocks in the district where these disturbed beds lie. It is possible, however, though there is no evidence whatever to support the suggestion, that there may be a rim of such older rocks lying below the level of the sea.

There is, as is generally admitted, good reason to believe that this portion of the continent stood, in the period extending from the close of the Trias to the beginning of the Cretaceous, at a much higher level than it does at present. During that time a broad river basin may have been excavated in which the Marthas Vineyard Cretaceous and Tertiary were laid down. I have elsewhere called attention to the fact that the Carboniferous beds of the Narragansett district and other local accumulations along the Atlantic coast appear to have been formed in drowned river valleys, and that the beds have since been subjected to mountain-building actions, the trends of the resulting folds having often departed widely from the trend of the neighboring axis of the Appalachian system. I am disposed to think that the Tertiary and Cretaceous beds of Marthas Vineyard have had the same general history, but the fact must be recognized that the evidence to support the conclusion is defective. All that can be said in its favor is that it is consistent with the basin-like origin and structure and the nature of the folding which characterize the localized mountain-built areas of the Atlantic coast.

We now come to the subject of the erosion phenomena of this district, and here we find ourselves in an interesting but difficult field. Beginning with the island of Marthas Vineyard—Capawok, as the Indian name has it—a district which gives us the most information concerning the structure and history of the field, we find there good evidence that the Tertiary and Cretaceous rocks have been subjected to a great amount of erosion since they were dislocated. On the western half of that island these beds rise to a height of about 300 feet above the present level of the sea. As there is an area of about 30 square miles where the crests of the divides have about the same elevation, there is good reason to believe that the existing topography was carved from a surface which, by base-leveling, or more likely by marine erosion, had been brought to an approximate level before the last Glacial period. If I am correct in supposing that there had been a tolerably complete base-leveling or benching with reference to a sea level above the tops of the present divides, then the development of the

present topography began long after the close of the mountain-building work.

The pre-Glacial topography of Marthas Vineyard has been but little disturbed either by glacial erosion or by the resulting drift coating. We can see that the course of the principal brooks—rivers, as they are locally termed—has been determined in general by the strikes of the beds coinciding therewith, while the smaller water courses cut across the folds in a normal way. The beds being all of slight hardness, the topography is smooth, but here we find sharp and continuous ridges which owe their relief altogether to differential erosion. These serve to show us how slight has been the wearing effected by the glaciers of the last ice epoch. The absence of such ridges on the remnants of the ancient upland plain also indicates that this plain was due to some action which wore it to a tolerably perfect level.

So well has the pre-Glacial topography of this island been preserved through the accidents of glacial invasion, that we can not only trace two or three cases of ancient stream robbery, but a close inspection makes it evident that all of the brooks of considerable size follow at the present time the channels they had before the ice came. In only two cases have I found that the morainal or other accumulations have changed in an important way the course of the waters. I note these points in order to show that the evidence from these streams as to the general drainage of the district is of value.

Taking the distribution of the brooks of Marthas Vineyard, we note that they are divisible into two groups—those which, turning south, fall into the broad ocean, and those which, descending from the northern side of the island, enter Vineyard Sound. The first-named group of brooks gives us little information except that they enter the sea through what appear to be drowned valleys, and are therefore evidence that the level of this land has been materially lowered since the existing topography was formed. The streams of the northern shore exhibit even more distinctly the same feature of drowning at the mouths, though this is marked, not by their entrance into lagoons, but by the filling of their channels near the sea level by moving sands. On this northern shore also we find in the distribution of the brooks the suggestion that when the land was at the level at which the river topography of the district was developed they entered a large stream occupying the central part of the broad valley now covered by Vineyard Sound.

The general structure of Vineyard Sound is easily misconceived. It has been suggested by Mr. Clarence King that the long range of the Elizabeth Islands, which form the northwestern boundary of this water body, is essentially morainal. There is undoubtedly a covering of morainal drift on the top of these islands, but on examination they prove to be composed mainly of beds similar to if not contemporaneous with the Nashaquitsa section. They probably contain also some part

of the Gay Head Tertiary beds. There are no good exposures, but enough is shown to make it clear that the Tertiary portion of that section is above the level of the sea along this line of islands. This condition of a sheet of moraine capping a divide is seen also on Marthas Vineyard, where the broader valleys are in their lower parts almost

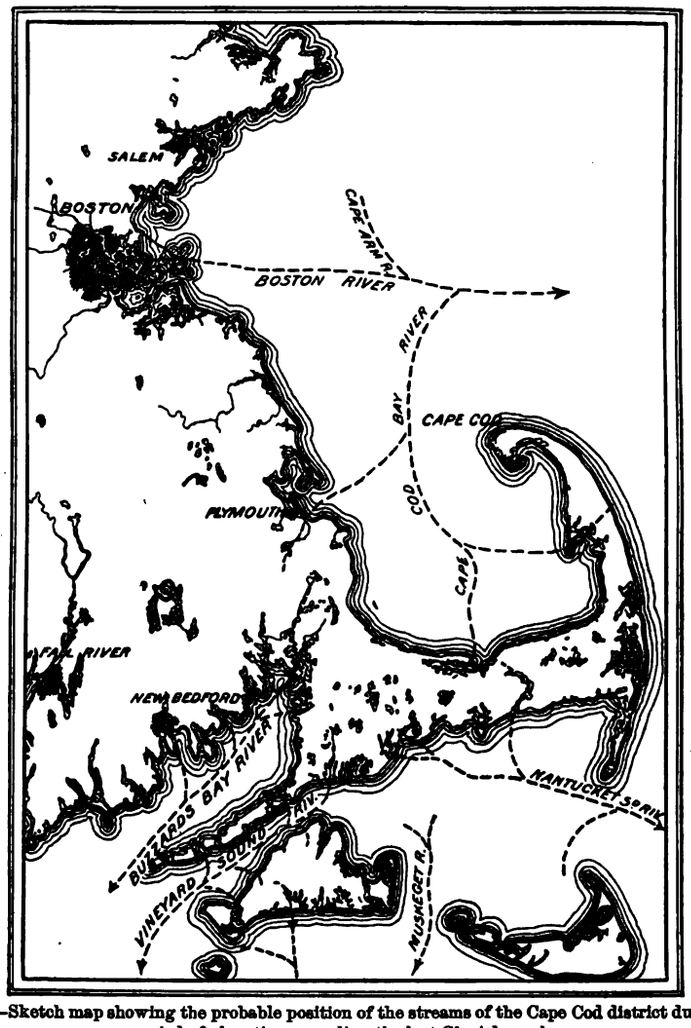


FIG. 86.—Sketch map showing the probable position of the streams of the Cape Cod district during the period of elevation preceding the last Glacial epoch.

driftless, while the crests of the ridges are usually crowned by a layer of morainal materials having a depth of from a few feet up to about a hundred feet. This feature goes to show that deposits of this nature tended to accumulate on the high ground. We shall have occasion to examine this matter more closely when we are considering the distribution of the moraines in the Cape Cod peninsula.

The fact that the Elizabeth Islands are not essentially morainal greatly increases the probability that the valley of Vineyard Sound was excavated by river action. The stream which occupied it during the period of elevation, when the erosive work was done, appears to have had its source on the southern side of Cape Cod. On the west of the Elizabeth divide, in the valley of Buzzards Bay, there was, if this conception of the history of the district be correct, another river which headed in the region about Wareham, taking about half its drainage from the district underlain by the ancient rocks of the mainland. In both these valleys we find the general features of drowned valleys exhibited quite as they are shown in the more southern bays of the Atlantic coast. The basins slope to the seaward, but not in a perfectly regular manner, for the reason that they are much encumbered by drift accumulations and by the waste that has been rearranged by the strong tidal currents which sweep through the bays and sounds of this district. They both widen to the seaward, as we should expect them to do if they had been excavated by the action of land waters.

The position of a third stream is perhaps traceable on the Muskeget Channel, which separates Marthas Vineyard from Nantucket. This headed against Cape Cod and against the upper tributaries of the Vineyard River, as we may call the stream which occupied the sound of that name. It is likely that to the inosculation of these headwaters we owe the formation of the channel which now separates the islands last mentioned from the peninsula of Cape Cod. In the sketch, fig. 86, the conception of the drainage of this district as it was before the last great upward movement of the sea is indicated. In such a figure it is inevitable that many features which are highly conjectural should be shown along with those which are well supported by evidence. In this case the doubt which is the most serious attaches to all that relates to the channels between the eastern end of Marthas Vineyard and the western side of Nantucket and between the last-named island and the mainland. As the tidal currents which flow through this water way are strong, some part of the erosion may have occurred both before and after the last Glacial period, at those stages of elevation and subsidence when the sea was free to pass through these channels. There is also a question as to the nature of the submarine ridges which so abound in these waters.

As regards the shoals of Vineyard and Nantucket sounds, it may be said that some of them, particularly those in the eastern portion of the last-named sound, are of moving sands, and, therefore, may have no relation to the continental topography. Some of these submerged ridges are more reasonably to be considered as preexisting, though their shapes may have been modified by tidal currents. Thus the long shoal, known as the "Middle Ground," which extends along the north shore of Marthas Vineyard from near the west chop of Holmes Hole halfway or more toward Gay Head is, as we may judge from the sound-

ings, a bit of submerged land topography. Although it is now the line of a strong division of tidal currents, and is consequently the seat of a "rip," this perturbation in the movement of the water appears most likely to be the consequence and not the cause of the elevation. So, too, in the case of the shoals to the northward and eastward as far as near Monomoy, there is nothing in the tidal movements which are competent to produce them, though the resistance which they offer to the movement of the currents has doubtless served to effect changes in their forms. If the statements of those fishermen and pilots who know these waters well may be trusted, these submerged ridges often contain on their surface considerable bowlders, which, if true, indicates that they are not in most cases the products of current action, but were formed mainly by subaerial agents of erosion.

It is to be noted that the channels south of Cape Cod to the west of Monomoy Point have in general a definite topography, characterized by steep slopes from the neighboring shores. This form of bottom seems to me inconsistent with the supposition that any great amount of sand is in the possession of the currents along these depressions. It is also noticeable that there is little trace of shifting sands along the shores on either side of Vineyard Sound. Furthermore, it is to be remarked that these valleys, as is shown by the protraction seaward of their very definite land slopes, have not been cut back on the average more than from 500 to 1,000 feet since the shore came to occupy its present level. All these considerations lead me to believe that the floor of these basins is not occupied to any great extent by drifting sands. For the reasons given above, the shoals to the east of Monomoy have been in general regarded as evidence of minor divides formed in the great submerged valleys.

The oscillations of sea level in this region have been more than once referred to in the preceding pages of this report. We have now to review the evidence, with a view to formulating it in a definite manner. It should be noted that there is in this district little, if anything, in the way of ancient beaches to afford data as to the altitude of the land in the periods which are under consideration.

On the mainland to the northwest of this region there are evidences of a base-level of river erosion or of marine planation, which Professor Davis and others regard as of Cretaceous age. The portion of this level at about 400 feet above the present shore line possibly corresponds with the present summit of the Cretaceous deposits of this island nearly enough to warrant the supposition that the sea stood at a height of some 400 to 600 feet above its present position when the lower Cretaceous of Marthas Vineyard was laid down. It should, however, be noted that those beds, owing to their dislocation by mountain-building action, may have been moved either above or below the general plane on which they were deposited.

It is evident that the lignitic portion of the Cretaceous beds was

laid down rather above than below the sea level, while the deposits containing marine fossils were formed below the plane of the sea. There is thus evidence of shore swaying in this portion of the section. As yet it has not been clearly determined which of these two elements of the Cretaceous lies the higher. The facts show, however, that in this part of the formation the shore was near its present level, and that it was instable.

Between the lower Cretaceous and the middle Tertiary there is a great blank, which includes the uppermost Cretaceous and the Eocene. As yet, the much-disturbed condition of all the beds showing the contacts of those horizons makes it impossible to say what measure of unconformity existed between them when they were laid down. It seems probable, however, that no mountain-building action had taken place in the district during this interval.

It is not yet perfectly certain that the middle Tertiary strata of this district were deposited in salt water. The marine fossils contained in the beds are found under conditions that admit of the supposition that they were not living when the strata were formed, but were swept in from previously existing deposits. I am forced to regard the determination of the age of this section as in some measure uncertain, but it is clear that it is newer than the Eocene and older than the Pleistocene. The general nature of the beds is most consistent with the supposition that they were formed in an estuary. Assuming that they were made at or about sea level, we should have to conclude that there had been no great change in the position of the shore line between the lower Cretaceous and the Miocene periods, or, what is more likely, that there had been a return of the seashore to about its same altitude in relation to the land after whatever oscillations it had undergone in this long interval.

In the Pliocene, as is shown by the fossils contained in the small locality, now destroyed, at the top of the Gay Head cliff, it is evident that, for a time at least, a shallow sea lay over the surface of the Tertiary beds, which were still in their horizontal position, for these Pliocene beds were evidently involved in the mountain-building movements. It can not be inferred that the altitude of these fossil-bearing Pliocene beds above the sea (about 100 feet) is evidence of a general upward movement of the shore, for the reason that the change of level may have been due to the folding of the strata.

The deposits of the Nashaquitsa series apparently indicate the existence of the shore line at least 100 feet below its present altitude. These beds may be regarded as closing the Pliocene record, and as formed, in part at least, before the orogenic movements took place.

After the series of constructive processes above noted had been accomplished, the beds of this district appear to have been established at a level some 200 or 300 feet lower in relation to the sea level than their present position. During the time in which they occupied this inferior level the upper base-level or bench of Marthas Vineyard prob-

ably was formed. It may, in passing, be remarked that the general topography of the bottom of the sea, from the southern end of Nantucket Shoals to Nova Scotia, is in favor of the supposition that we have in this district a surface that preserves in a general way the contours impressed upon it by subaerial erosion.

The down-sinking of this region some time during the Glacial period probably brought about the drowning of the great valleys. It evidently resulted in a lowering of the land at least 100 feet below its present altitude, as is shown by the fact that the morainal aprons or sand plains which are so conspicuous a feature in Marthas Vineyard, Nantucket, and Cape Cod attain about that altitude. These aprons are, as elsewhere noted, composed of sand and gravel, with occasional bowlders of considerable size, which evidently attained their present sites by ice rafting. They have, however, a characteristic submarine topography, such as could not well have been made by any form of subaerial action. The "scour ways" noted in the report on Marthas Vineyard[1] as existing on these aprons are of themselves sufficient to establish the presence of the sea over these plains.

As yet there is no evidence concerning the upper limit of this submergence, which occurred in and possibly before Glacial time. After a careful search throughout southeastern New England, the shore line of the sea in the time when the morainal aprons were formed has not been found. Here and there, at the height of about 200 feet, there are what may be faint traces of a coastal shelf, but they are too indefinite to afford any clear evidence of such a line. The distribution of the drift in the southern part of Marthas Vineyard, in the towns of North Tisbury and Chilmark, is such as to suggest that the glacier did not, save in certain small tongue-like projections, extend south of Tisbury River, and that the drift south of that stream was all rafted to its present site. If this view be confirmed by closer study of the deposits, it will affirm the hypothesis that the whole of the island was under water, for the materials which appear to have been thus transported are found on the very highest land, at an elevation of 300 feet above the sea.

I have elsewhere[2] endeavored to show that on the southern face of the hills of Mount Desert, Maine, we have good evidence of a depression at the close of the Glacial epoch amounting to at least 1,100 feet, and possibly extending up to the highest summits, or 1,527 feet. It seems likely that a depression of even the lower of those levels on the coast of Maine would have involved a submergence in the region of Cape Cod sufficient to have covered the highest lands in that vicinity. It thus appears probable that the Glacial submergence of this district carried the whole of its area below the level of the sea.

The emergence of the Cape Cod district from the Glacial depression must have been very rapid, for the surface appears substantially as it

[1] See Seventh Ann. Rept. U. S. Geol. Survey, 1885–86, p. 316.
[2] See Eighth Ann. Rept. U. S. Geol. Survey, 1886–87, p. 1009 et seq.

was left by the ice. The delicately molded topography of the drift has not been effaced by wave action, nor, as before remarked, are there any traces of ancient beaches. At first sight this absence of any effect of the waves on the surface seemed to me clear evidence that the area could not have been under water since the disappearance of the glacier. In order to determine this point, I visited the region below the elevated beaches in central New York, and found there the same unaffected conditions of surface which exist in southeastern Massachusetts. The conditions of submergence and emergence must have been approximately the same in both areas. It appears, therefore, that we have to accept the conclusion that the uprising of the land after the Glacial period was so sudden that the waves and shore currents did not have time to do effective work. It is possible, however, that the waters were at this time so far obstructed by floating ice that no great amount of wave action took place during a considerable length of time in which the elevation was going on. The last change of level of the Cape Cod district evidently brought the land somewhat above the plane at which it at present stands. This is shown by the occurrence at various points of submerged forests, as in Nantucket,[1] and in the marshes bordering the harbor of Holmes Hole, Marthas Vineyard. The amount of this recent downward motion is not known, but it may have been sufficient to obliterate the land connection which united the islands of Marthas Vineyard and Nantucket with the mainland. The reason for supposing a connection between these islands and the mainland is found in the substantial identity of their faunas and floras with those which exist on the neighboring continent. Considering the width and current-swept nature of the sounds which separate those islands from the mainland, it appears unreasonable to suppose that all these species of animals and plants could have found their way to the outlying stations in the short time which has elapsed since the Glacial period. The conditions of passage are almost as difficult as they are at the straits between the islands of Bali and Lombok, which separate the biological provinces of Australia and southern Asia. As there has been a subsidence since the forests regained possession of these islands, it is reasonable to suppose that the previous elevation was great enough to bring about a connection with the mainland.

It is to be noted that the changes in the relative elevation of sea and land have all been spoken of as if they were due to changes in the altitude of the land. It should be observed that this assumption is incorrect. There are at least two main and efficient causes of alteration in the position of the sea in relation to the land, as well as many others of minor importance which probably have some value. One of these, local in its nature, is the swaying of the land against which the sea lies; the other is change in the form of the sea bottom affecting the height of the open waters along all the shore. It is rarely possible to differentiate these causes. In the case of the Iroquois beaches in central New

[1] See Bull. U. S. Geol. Survey No. 53, p. 28.

York, the fact that they rise to the north supplies a criterion, the like of which may be found in other places, which indicates that the post-Glacial elevation was due to a land movement. Again, as I have elsewhere endeavored to show,[1] the very general drowning of the lower valleys of the rivers of all the continents affords evidence that there has been, in very modern times, a general rise of the sea level to the amount of 100 feet or more. It is to this general inundation that we may perhaps attribute the destruction of the land bridge which for a long time after the close of the Glacial period united the New England islands with the mainland.

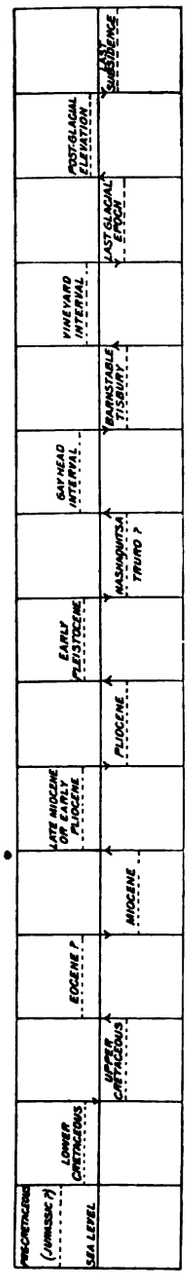


FIG. 87.—Diagram showing the probable movements of the Cape Cod district since the Jurassic period.

There is some evidence as to the duration of this land bridge to be derived from the possible rate of marching of the oaks and other heavy-seeded trees northward from their southern refuge during the last ice time. These trees, in the process of repossessing an abandoned field, do not, according to my observations, advance at an average rate of more than 5 feet a year. To assume a rate of 10 feet a year would be to allow the utmost that could be supposed. This would require about 500 years for a mile of journey, or about 2,000 years for the passage across a land bridge from the mainland to the island of Marthas Vineyard. I have elsewhere urged this slow rate of northward march of the heavy-seeded trees as an argument against the hypothesis that the close of the glacial advance, when the ice lay at the southernmost point it had attained, was not more than from 10,000 to 20,000 years ago. If the argument be valid, the return of the oaks to southern New England, after their expulsion to regions farther south, must have required somewhere near 200,000 years.

It is possible that some of the topographic features of the submerged channels of this area are due to the erosion which took place during the elevation that followed the Glacial period. The cutting away of the divide between what we have supposed to be the drainage basins of the Vineyard and the Muskeget rivers may have been in part effected by the energy of the tidal currents, which, in case the passage were diminished in sectional area, would act with something of the strength they now have in passing from Vineyard Sound to Buzzards Bay through the shallow passage known as Woods Hole.

[1] See Bull. Geol. Soc. Am., 1895, p. 153 et seq.

We have next to consider the erosion performed in this district by the ice of the Glacial epoch. It is now well known that the original conceptions as to the amount of this wearing on the general surface of the country were very much exaggerated. There are few students of the phenomena in the field who would be disposed to believe that the average of this erosion in New England amounted to as much as 100 feet. I doubt whether it was as much as 50 feet. It has commonly been supposed, however, that in incoherent materials the action was more effective than in firm-set, highly changed rocks. So far as we can judge from the conditions seen on Marthas Vineyard, where the contact of the drift with the underlying sands and clays is well revealed by the cliff sections and the clay pits, the glacier did little more than smooth over the soft materials without effacing their original outlines. In no case is any considerable amount of the characteristically colored clays and sands mingled with the till covering. It is usually impossible to find a trace of them at a height of 2 feet above bed rock. When we consider that this occurs at points where the ice has journeyed for a mile or more over the soft beds the absence of all marks of erosion is seen to be very remarkable.

I have already noted the fact that the glacier failed to destroy even the minor features of the topography of this field. It is difficult to exaggerate the extent to which the pre-Glacial topography survives in the Vineyard area. The facts must indeed be seen, and this carefully, to be appreciated. There is one way, however, in which the glacial conditions effected a considerable amount of local erosion in this district. This was by the action of the subglacial streams which flowed upon the surface of the bed rocks. All along the northern face of Marthas Vineyard we may trace these subglacial river ways, which extend from the shore in winding, sometimes beautifully curved, channels cut down into the soft rocks to where they discharged beyond the front of the ice. Sometimes these channels are coincident with earlier-formed valleys. Again they are carved where it is evident that open-air streams have never flowed. The largest, and in some ways the best, example of these interesting and elsewhere unnoted features is seen at Chappaquonset or Tashmu Pond and in the valley which continues the depression to the southward. As elsewhere noted, these grooves, extending from the shores of Vineyard Sound upward, terminate on the south in the morainal apron, or, rather, are continued over that apron in other shallower and wider troughs cut in the sands which extend downward to the ocean shore. In some cases the bottoms of the grooves which were under the ice have been worn down to the depth of 60 feet or more into the soft bed rocks.

It is likely that the low places in the Elizabeth Islands divide, as at Woods Hole, Quicks Hole, and Robinsons Hole, as well as certain others which do not go below the level of the sea, are due to a like action of subglacial streams when they crossed the ridge lying between

the sound and the bay. Similar valleys will be noted in the detailed account of the structure and topography of Cape Cod.

We have last to consider the extent of the post-Glacial marine erosion which has occurred in this district. This has been and is still great; at present it is some hundredfold greater than that done by land waters, but the distribution has been in certain regards peculiar. As before noted, the marine benching of this district which occurred after the deposition of the Pliocene strata was apparently pushed to the point where the whole area of the Cretaceous and Tertiary rocks was brought to a level. This may possibly have been due to base-leveling by stream action, but whoever will observe the practical absence of such work on the strong topography of Marthas Vineyard, where the brooks are never colored by the soil waste and where there is not a single stream scar, will hesitate to hypothesize this slow process of lowering to a common level such rocks as here occur. There are on Marthas Vineyard pretty clear evidences of the existence of a second level of marine benching at the height of about 150 feet above the sea. This bench is recognizable around nearly the whole of the western elevated section of the island, and as there is no structural basis for it it must be regarded as of marine origin. Its original width can not now be determined with accuracy, for it is much diminished by marine erosion, but on the average it can not well have been less than one-third of a mile, and may have been more than twice as great as that amount. Thus the pre-Glacial erosion due to the sea apparently includes two large operations, the formation of the original level surface of the island and the cutting of the lower bench, which was a much less extensive work. As to the benching which may have been done in the sections below the water level, the evidence, though in a way interesting, is too perplexing to warrant discussion.

The post-Glacial marine erosion of this district has been extensive and is now in process of very rapid development; no other portion of the coast of North America is undergoing such a complicated and rapid readjustment. When the problems which are there presented concerning the action of the sea on the shore and the arrangement of the detritus derived from the process of erosion are worked out, this area will become the classic ground for students of coastal action. For our purpose it will be well to divide the question into two heads, the first relating to the amount of erosion already done, the second concerning the manner in which the work is effected.

In this, as in most other shore lands, the only possible way of determining the extent to which the sea has gained on the land is to take the slopes which extend downward to the sea and ascertain where, if protracted, they would cut the water level. This method is particularly applicable on shores such as those of southeastern New England, where there is a gentle slope toward the sea. On this basis, using for data observations made at some scores of points, I have come

to the conclusion that if the land had been stable since the last ice time the average retreat of the shores might safely be estimated at rather more than about one-half a mile. Unfortunately for the sufficiency of this method, it is certain that there has been a subsidence, which may be, and most likely is, now going on, so that the resulting work of the sea is not the formation of a horizontal shelf but of a sloping scarf, much of which is submerged. Thus we can only say that, the rate of the down-sinking being unknown, we are deprived of any means of accurately fixing the extent of the incutting since Glacial time, and are driven to the ruder method of noting the amount of recession of particular cliffs.

Turning to the evidence afforded by the cliffs, the best obtained is that due to the surveys of the late Prof. H. L. Whiting, long the senior assistant of the United States Coast and Geodetic Survey, who fixed the rate of erosion of the Nashaquitsa cliffs by very careful observation for a period of fifty years at 3 feet per annum.[1] The evidence is clear that this is the rate for nearly if not quite the whole southern shore of Marthas Vineyard. At Gay Head there are only approximate data, which serve to show that most likely the retreat does not amount to as much as a foot per annum. Along the north shore of Marthas Vineyard the process of erosion is very slow, save at a few salient points west of the steamboat landing. At West Chop the rate does not average a foot in five years, but at the east and west chops of Holmes Hole the cliffs have for some years been retreating at an average rate of at least 2 feet per annum. This wearing is probably in some way connected with slight alterations of the shoals which direct the tidal currents against the shore. On the Cottage City or eastern face of the island the rate of wasting is also great. The recession of the shore has amounted to at least 30 feet in fifteen years, and this despite some slight efforts made to resist the action of the waves. The region near Edgartown is amply protected on its east side by the extensive system of hooks about Cape Pogue. As a whole the shores of Marthas Vineyard in process of erosion, excluding the island of Chappaquiddick and the Cape Pogue hooks, are probably entering the land at an average rate of about a foot a year. The mean height of the sea-cliff face may safely be taken at 30 feet, and the total face subjected to erosion at 35 miles. This would make the quantity of material removed amount to a total of about 1,000,000 cubic feet per annum.

On the island of Nantucket, owing to the extent of the sand-barrier beaches, the proportion of the total shore line which is exposed to active erosion is less than that of Marthas Vineyard, but the wearing action of the sea is much more effective, for the reason that clays rarely appear in the escarpments, which are mostly of stratified drift, such as is found in the morainal aprons. The southern shore of the island and a portion of its northeastern face are apparently retreating at the rate of

[1] Geology of Marthas Vineyard: Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 361.

more than 4 feet per annum. Yet, for the reason above given, it seems likely that the average encroachment of the sea is much less rapid than it is in the island of Marthas Vineyard.

The Elizabeth Islands are wasting for the greater part of their length, but the process is now being arrested by a simple action which has brought protection to much of the shore lands of southeastern Massachusetts. The mass of these islands is, as before noted, of incoherent sand, but the surface is generally occupied by a layer of coarse till or moraine, having a depth of a few feet. As this pebbly and bowldery matter falls to the shore it forms a stony beach. This plating over the soft underlying beds is sufficient to prevent the shore currents from wearing them away. The result is that a platform is made on which the waves break before attaining the shore, and often a barrier beach is formed which to a great extent keeps even the swash from attaining the cliffs. When the adjustment has gone thus far, the shores erode only so fast as is necessary to supply the place of the pebbles which are worn out or the larger waste brought about by the action of the shore ice in rafting away the stones, as it does in a very effective way. An excellent example of the value of these conditions in hindering marine erosion is shown at Gay Head, where, despite the ease with which the strata slip downward into the sea, the vigor of the assault of the waves, and the complete and rapid removal of the sands, the retreat of the escarpment is slower than that of many other less exposed shores on this part of the Atlantic coast line. The bowldery drift, though not large in amount, is enough to have formed a shelf extending irregularly out from the face of the cliffs to the distance of nearly a mile. On this the heavier seas break, so that when running from their prevailing direction only the secondary waves attain the shore, with so little effect that the retreat of the face is at the present time less than a foot per annum and appears to be rapidly diminishing in its rate. On the other hand, the Nashaquitsa cliffs, which in their retreat contribute but little bowldery material to the sea, are, as above noted, retreating at the rate of 3 feet a year, the sea having no difficulty in deepening the bottom as it works in, so that its waves are able to assault the base of the cliffs.

On the peninsula of Cape Cod we find evidence of marine erosion essentially like that on the islands which lie to the southward. The details of this action will be noted in the section of this report which is devoted to the topography of that area, but the general features may well be considered here. The most interesting point is that probably all of the invasion of the sea occurs on the southern and eastern (or outer) part of the peninsula, there being little trace of it on the northern (or inner) shore. This is in part for the reason that the seas strike in times of heavy storm with greater effect in this portion of the coast, but in larger measure it is owing to the fact that strong tidal and shore currents sweep by this part of the coast, which carry away the

débris delivered to the sea by many of the cliffs, so that it does not encumber and protect the shores.

On the northern shore of Cape Cod the surface has, as will hereafter be noted, a long riding slope of the glacier, composed usually of clay, which descends gradually to the sea level. This slope extends from the western border of the town of Barnstable to Yarmouth and is partly indicated as far as the town of Brewster. Where this gentle declivity passes beneath the sea, or where it attains the fit depth of water, a beach is formed which incloses the great marine marshes that are so prominent a feature of this part of the coast. This beach is slowly working inland, but the amount of sand which accumulates in the bay it faces is so great that the excavation of the bottom necessary to the inward march of the beach hinders the movement.

On the north shore of Cape Cod the distribution of the products of coastal erosion indicates the weak action of marine currents. On the south side, in the waters between Hedge Fence Shoal and the open sea to the eastward, the distribution of the shoals and spits shows a considerable amount of movable débris in the possession of the sea and its conveyance by strong currents. In the field about Monomoy the struggle between the accumulating sands and the currents is so active that there is evident danger of the passage to the seaward between Nantucket and the cape being closed before many decades have elapsed. If in any time of great storm this channel should become so shallowed that the waves would break across it, the result would be the immediate construction of a barrier beach. If this construction failed to attain to or near the surface, it would doubtless be swept away by the tidal currents. If, however, it made an effective barrier to their flow the island of Nantucket would be again joined to the mainland. An accident of this nature is possible; it is likely, indeed, to be the next great change in the conditions of this part of the Atlantic coast.

As before remarked, the unstable sands of the bays on the eastern side of Cape Cod appear to be mainly limited to the eastern portion of these waters. In Vineyard Sound the evidence from the shores and soundings indicates that the amount of sand at the disposition of the currents and waves is not large. The shores are generally pebbly and the soundings are not to any extent variable. The harbors, such as Tarpaulin Cove, Woods Hole, Holmes Hole, and Edgartown, though so placed that they would naturally be obstructed by moving sands were large quantities of such materials in unstable positions, show little tendency to fill in. The sand beaches, such as those at Menemsha light and between Sengekontacket Pond and the sea, are evidently not gaining in width. These conditions are in very distinct contrast to those which are found in and about Nantucket Sound and Muskeget Channel, where there is a ceaseless oscillation of the shoals and where the harbors which exist are in constant process of closure, against which, as at Nantucket, the precautions of the engineer seem to be of little avail.

The reason for this difference is not perfectly clear; it is probable that it is in part due to the relatively large amount of waste contributed to the sea by the degradation of the shores of Nantucket and Cape Cod, but in a measure also to the fact that the average run of the tides seems to bear the sands to the eastward to a point where the energy of the Atlantic surges, rolling in from the eastward, tends to beat them back into Nantucket Sound.

It seems likely that something like this peculiar condition which we now find in the shoals of the Monomoy group existed a short time ago in the region of Nantucket Shoals, although as yet we do not know enough of these shallows accurately to determine their history. It is probable that it represents the remains of a system of low islands, shoals, and tidal channels which were depressed beneath the sea at the last subsidence. If we should conceive the shore to be 50 feet higher than it is at present, the struggle of the tides and other currents which now exists about Monomoy would be transferred to the region of Nantucket Shoals.

UNDERSTRUCTURE OF CAPE COD.

On first inspection the body of Cape Cod, i. e., that part of it which lies between Monument River on the west and the sand spit which sets in just east of Highland light, appears to be made of glacial débris. It is true that nearly the whole surface is covered either by the extensive moraines which are to be described in the next section of this report or by the deposits of sand and gravel which are spread on the south and east of the morainal accumulations. These superficial accumulations are so extensive that they very effectively mask the true character of the underlying deposits. None of the streams form sections which reveal the underlying beds, and the only cliff shores which do this are near Highland light, where the evidence, as will hereafter be noted, is not very indicative. I therefore deem it necessary to give in some detail the evidence which goes to prove that there are large areas of relatively old strata lying beneath the glacial beds of this district and above the level of the sea.

Beginning with the southwestermost portion of the cape district, that which is in the town of Falmouth, we observe in the fields about Quamquisset Harbor a quality of surface which clearly indicates the existence of deposits other than those of glacial origin. The topography is evidently older than the last ice time, the valleys being somewhat encumbered with deposits of drift. Sections through the ridges show beneath the thin detrital coating a series of somewhat indurated sands, gravels, and clays, usually thin-bedded, though some of the clay layers are 2 feet or more in thickness. The sands and gravels are rather ferruginous, and sometimes the iron oxide is sufficient in amount to produce a distinct cementation. The clay beds range in color from whitish, through brown, to distinct reds. The materials and their

association are essentially like those belonging to the Nashaquitsa series, as shown on Marthas Vineyard. The pebbly matter is rarely of crystalline rocks; it consists almost altogether of quartz and quartzite. In the places where shown in rather small openings it seemed likely that the few pebbles of a granitic nature had been brought to the ground by the glacier and crushed into the mass by ice action.

The most notable feature in the "Quisset" Harbor section is the considerable dislocation to which the beds have been subjected. The layers are thrown into short, abrupt folds, the resulting dips being at several points as much as 30 degrees of declivity. The strikes are irregular, but, as on much of Marthas Vineyard, incline to a general northwest-southeast direction. The condition of the folded beds, especially the fact that a topography somewhat obstructed by glacial deposits but otherwise undisturbed was carved on them in pre-Glacial time, clearly indicates that here, as on the island last named, the disturbances can not be accounted for by the movement of the ice. The important exposures which have yielded this evidence were made in 1896 by a land company in grading the roads of its property. They are, unfortunately, of a nature to be soon effaced.

The topography and the distribution of the "spring levels" (or places where the water contained in the drift is turned to the surface by the clays) of the region about Woods Hole indicate that this Nashaquitsa series—for such we shall term it—rises to the prevailing height of about 60 feet above the sea, being capped by the ridge of the moraine which runs parallel with the shore of Buzzards Bay. Northward along the shore of that bay the conditions of surface, as explained by the above-noted facts, indicates that essentially the same materials continue to Buzzards Bay, the ancient series being interrupted only by the indentations which are formed by several "drowned" valleys and by Monument River. In a railway cutting just west of Buzzards Bay station there was exposed in 1896 a section about 4 feet deep which showed stratified ferruginous sands that were slightly folded. These beds appeared to belong to the same series as those at "Quisset" Harbor.

Just east of Falmouth the stream beds near the shore at several points reveal by a little excavating the presence of indurated ferruginous sands and gravels of the same type as those found north of Woods Hole. Moreover, the streams that drain from the eastern face of the Falmouth moraine show that the percolating drainage which is normal to a sand-plain country is interrupted by some resisting layers, which hold the water near the surface. If there were not water-turning beds under these sand plains they would, like those of the similar plains of Marthas Vineyard and Nantucket, drain by percolation to the sea.

The facts above noted warrant the hypothesis that the western section of Cape Cod, say for a strip some 8 miles in width, has a foundation of ancient sands, gravels, and clays which rises to a considerable height above the water level, and is, in parts at least, much dislocated.

It is barely possible that the unseen water-holding layers on the eastern side of this area are of till or other clay beds of Glacial age, but the improbability of this view will be made apparent by the account of similar deposits in other parts of the cape.

On the northern shore of the peninsula, from near Monument River eastward to Yarmouth, and less distinctly still farther eastward to Orleans, there is an often indistinct but clearly traceable slope leading upward from the sea level to a height of 60 feet or more. This slope is often more or less masked by local accumulations of till, or even by small ridges of a morainal nature; but wherever its structure is revealed it is found to be made up of a deposit of dark-blue and gray stratified clays. Its presence is generally attested by the fact that it is not penetrable by water, and the fields which lie upon it are quite different in character from those found elsewhere in the cape district. The agriculture of the northern portion of Barnstable County has indeed been to a considerable extent founded on the quality of this underlying material, which affords a much more enduring soil than is found elsewhere in the area.

Occasional wells on this northern slope of the cape, and particularly the brick pits in Barnstable, show this clay to have the thickness of at least 20 feet. At no point, so far as I have been able to find, has it been passed through.

The clay which so generally forms the northward slope of the cape, between Orleans and Monument River, apparently underlies all the characteristic deposits of the last Glacial epoch. Upon it rests a number of small areas of an evidently morainal nature, as well as a general though rather thin covering of till, which appears at some points, particularly at the brick pits above referred to, to be somewhat churned up with the lower clay. Nevertheless, the distinction between the two deposits is sufficiently clear to show that they are only accidentally associated. Although this clay is to a great extent masked by the usually thin coating of drift, it appears to be continued as a tolerably connected deposit from the western extremity of the cape to Orleans, and perhaps still farther eastward. The fields of this section owe their relative fertility in part to the fact that the clay keeps the water table nearer the surface of the ground and in part to the commingling of this clay with the glacial waste, which in this district is distinctly more clayey than it is in other parts of the cape.

The northern clay of Cape Cod does not appear to have been dislocated by compression strains, at least none such have been seen in the scanty sections which are exposed to view. As to the origin of the deposit, the evidence is not yet clear. So far as ascertained, the material contains no fossils. In its general aspect it is like the well-known brick clays of southeastern Massachusetts, which were, in some cases at least, clearly formed at the time of, and in front of, the glacial sheets during the last ice advances. Yet, as no pebbles have been found in

the deposit, and as its resemblance to some of the beds of the Nashaquitsa series of Marthas Vineyard, which clearly antedates the last ice epoch, is evident, it will not be safe to class it as of Glacial age. It is, perhaps, the equivalent of the Tisbury clays of Marthas Vineyard.

South of the glacial clays, and generally beneath the moraine which extends from Monument River to Orleans, the evidence, though imperfect, goes to show the existence of another series of clays, which exhibit a general likeness to those noted as occurring in Falmouth near Quamquisset Harbor. In my opinion this ridge of older clays forms the greater part of the considerable elevation, which at first sight appears to be entirely of a morainal nature. The evidence in support of this proposition is as follows:

Along the line of the moraine, which attains at several points an altitude of nearly 200 feet, we find that the depressions of the surface, up to 150 feet, often contain water for a large part of the year. Even where they are not temporary pools, these kettles commonly exhibit up to or above the last-named height a degree of wetness which indicates that they rest upon more impervious materials than the very porous moraine affords. An index of the same nature is to be found in the height of the considerable lakes, of which a score or more are shown on the topographical map of this part of the cape. Thus, Peters Pond, in Sandwich, is about 95 feet above the sea, and a number of the other lakes exceed 50 feet in altitude. In general, it may be said that the lakes in the central portion of the cape, particularly those within the limits of the distinctly moraine topography, stand at heights above the sea which clearly indicate that the barriers which retain the water are much less pervious than the sandy, pebbly, and bowldery matter of the moraine itself, which in this regard is but slightly more effective than the washed drift. The same considerations lead us to extend the clay area much to the southward of the southern face of the moraine. The lakes on the sand plains for some distance out from the face of the moraine lie at heights which exclude the supposition that their waters are retained by the interstitial friction or resistance to percolation which is normal to washed drift. On the sand plains of Marthas Vineyard the value of this friction, as is shown by the depth at which water has been struck in the central portion of the island, is not more than 2 to 3 feet to the mile. On Cape Cod many of these lakes of the plain are at heights above the sea which would afford grades of from 12 to 15 feet to the mile from their low-water mark to mean tide. On this account, as well as from the general statement which is had from all those who are familiar with the history of the wells of the district, that they usually strike clay before attaining the level of the sea, I judge that the central clays of the island probably extend some distance south of the moraine.

As to the character and altitudes of the central or submorainal clays of the northern part of Cape Cod, the evidence yet gathered, though

not extensive, is, taken with what has been found near Woods Hole, sufficient to show something of these conditions. In the section between Great Pond and West Barnstable the roads show some small sections of grayish-white bedded sands unlike any glacial beds known to me. The beds dip to the southeast at angles of from 8 to 10 degrees. Traces of reddish-brown clays are revealed in the same district.

In the town of Dennis, at the side of the State road, the cuttings at the time they were made revealed dark clays and gray sands, thinly bedded, resembling the Nashaquitsa series. These beds are folded on a north-south axis, the amplitude of the arches, so far as could be ascertained, not exceeding 50 feet. Although these foldings were not very plain, they were recognized by my companion, who had no special knowledge of geology, as arches having the form shown in the diagram, fig. 88.

In the town of Brewster, about one-half mile east of the station of that name, there is a considerable area (100 acres or more) in which the drift covering is so thin that the under clays are revealed. These appear to be somewhat confused next the surface by the rubbing and scouring action of the glacier. It is thus impossible, in the slight exposures, to determine the exact attitude of the beds, which are of grayish and blue sandy clays and red clays, the last of the general aspect of those at Gay Head. Near Griffiths Pond—now a cranberry bog—a considerable exposure of the red clay on the north side of the road to the station shows not very clearly a rather steep dip to the northwest. Although the scanty showing of these clays in the small pits by the roadside does not afford distinct evidence of steep dips, the distribution of the outcrops indicates such attitudes, with a prevailing strike N. 45° E. These clays rise to about 100 feet above the level of the sea.

FIG. 88.—Diagrammatic section showing position of folded clays, State road, Dennis. A, glacial drift; B, folds in (Truro?) clays. 1 inch = 100 feet.

From Schoolhouse Pond to East Brewster station the clays, apparently of the same general nature as those last described, lie everywhere near the surface on the south side of the main road. The deposit rises to the height of from 100 to 110 feet above the level of tide. Its upper surface forms a tolerably gentle slope to the northward, on which rests the morainal heaps and into which the kettles seem to be cut, with the result that they are usually very wet at their bottoms. The red or reddish sandy clays appear also, though obscurely, in some of the roads of East Harwich which lie to the south of the section last described.

In Orleans the older series seems to be present thoughout the greater portions of the area of the town. It is scantily revealed in the road

cuttings, and is shown in an effective way only on the southwest side of Town Cove, just east of Tonset. Along this shore the deposits are not enough exposed to give a clear idea of their attitude. They are all dark colored and are related to the glacial beds in the manner indicated in the accompanying diagram, fig. 89.

The above-described clays appear to continue for some distance northward into Eastham. The precise line where they cease to rise above the level of the sea has not been determined; it can not be ascertained without pits or borings. It seems likely that this limit is not far from North Eastham station.

On the south side of the moraine there exists a series of clays which are revealed in the ordinary domestic wells that are driven in this section. I have been unable to find any of these wells in process of excavation, and am therefore limited as to information concerning the section to what I have been able to gather from various persons whose

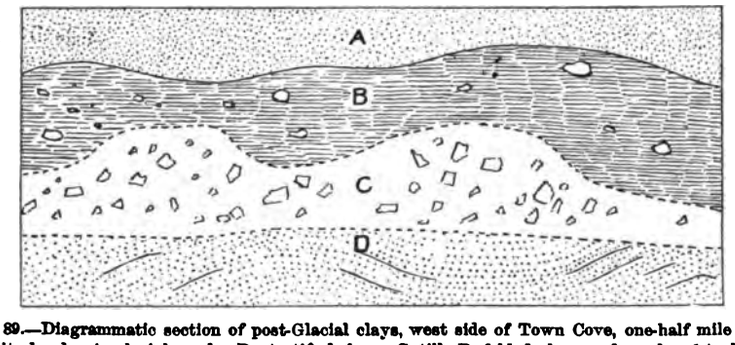


FIG. 89.—Diagrammatic section of post-Glacial clays, west side of Town Cove, one-half mile south of its head. A, glacial sands; B, stratified clays; C, till; D, folded clays and sands. 1 inch = 10 feet.

statements seem worthy of trust. These persons agree that for a considerable distance south of the moraine in Harwich, to within a mile or so of the sea, these wells strike a dark-colored clay ordinarily at a depth of 10 to 20 feet below the surface. This deposit usually has to be passed through in order to obtain water, which is found in thin layers of gravel above a lower-lying clay. The thickness of the upper clay is said to be 10 feet or more; the lower clay deposits do not appear to have been passed through.

The statements concerning the existence of a series of clay layers beneath the sand plain on the southern side of the Cape Cod moraine are in accordance with the evidence afforded by the levels of the lakes in this area. As before remarked, these lakes, especially those which are situated within 2 or 3 miles of the morainal area, have a height above the level of the sea which is inconsistent with the supposition that they are fenced in by no more effective barriers than would be formed of the open-textured sand and gravel of the plain in which they lie. These lakes are, in part at least, to be regarded as occupying old val-

leys, which slope down to the northward and have been barred across by morainal accumulations of a clayey nature, which have in good part effaced them.

As to the attitude of these clay beds, which lie beneath the whole or a large part of the southern morainal plain of the cape as far out as Orleans, there is no basis for accurate determination. The reports from those who have sunk wells in the area leads, however, to the supposition that the deposits are not dislocated after the manner of the central series, but lie in approximately horizontal attitudes, dipping gently to the southward. It is thus tolerably clear that the fundamental structure of the body of the cape—at least that part of it lying between Monument River and Eastham—consists of a central axis of more ancient clays and sands, having in part at least the general aspect of the Nashaquitsa series of Marthas Vineyard, and being likewise much disturbed by orogenic action. On the flanks of this older axis of elevation lie the clays, which, as before noted, appear to form the north and south slopes of the area, and on which rest the relatively thin layer of glacial waste—the moraines and sand plains which give the surface aspect to the region.

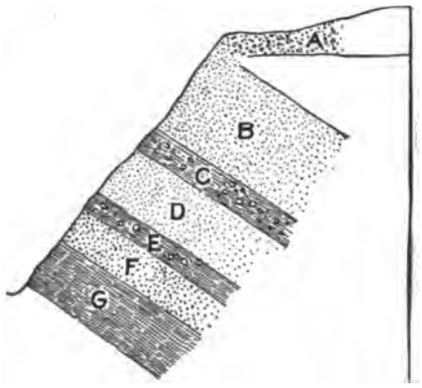
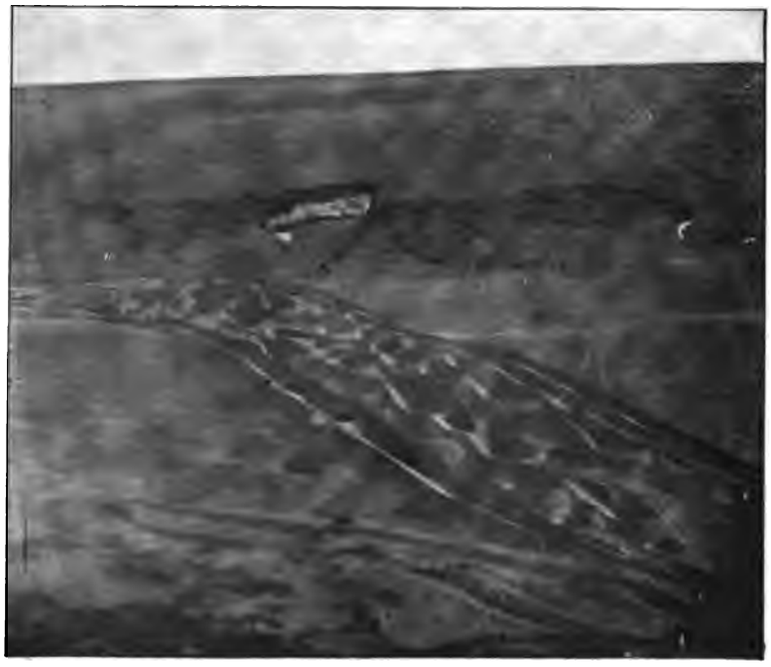


FIG. 90.—Diagrammatic section near Wellfleet bridge, in Truro. A, glacial drift; B, D, F, stratified sands; C, E, pebbly sandy clays; G, fine clay. 1 inch = 5 feet.

The outer portion of the cape—i. e., that between Orleans, or perhaps the northern portion of Eastham, and the extremity of the peninsula—has a structure which indicates a history somewhat different from that just noted. In this outer part the older dislocated beds with the red clay layers do not appear above the water level, or if they rise above that plane they are completely covered by the later-formed deposits of clays and sands. In this area we have a succession of beds, indicated in the accompanying fig. 90, which shows a series of events somewhat different from that exhibited in the district to the westward. In this section, from central Eastham to the end of the highland at Moon Pond and Salt Meadow Pond, the beds consist of certain clays which appear, so far as can be determined by their general nature and relations, to be essentially similar to those beds which were noted as occurring on either side of the Nashaquitsa series of the western district of the peninsula. Upon these clays occur beds of much-decayed sands and gravels, which in character are somewhat like those found in the subglacial portion of the section on the west side of Town Cove in Orleans. Owing to the large showing made by the glacial deposits of

A. DUNE POND, PROVINCETOWN.



B. NEAR VIEW OF DUNE SURFACE, SHOWING MASS OF BURIED SNOW.

this part of the cape, this series of sands and clays has been assumed to be the product of the ice age. Although the question as to the age of the several divisions of rocks of this field is in the main to be dealt with in a later part of this report, it may here be said that there is good reason to doubt whether the beds shown in Wellfleet and Truro should be reckoned as of glacial origin, at least in the sense that the sand plains in the more eastern section are to be so reckoned. They have exhibited no glaciated pebbles; they lack the surface slope so characteristic of morainal aprons, and they fail to exhibit the occasional large ice-rafted bowlders so common in such deposits.

From the northern end of the highland of the cape to the extremity of the peninsula the land is, so far as its surface is concerned, made up altogether of sands, which have been brought into their position by the recent action of marine currents or of the wind. As has been shown by Professor Davis, the form of the slope which terminates the elevated ground toward Salt Meadow Pond indicates marine erosion before the outermost part of the cape had been built. As will be hereafter noted in more detail, this agglomeration of sand hooks and spits most likely rests upon a portion of the land which had been cut away by a set of currents different from those now prevailing on this shore.

FIG. 91.—Diagrammatic section across Cape Cod from West Barnstable station to Osterville, showing the general structure of the area west of Orleans.

The construction work involved in the formation of dunes is admirably shown in this portion of the cape. By the exercise of a certain amount of care in planting, the local and State authorities have succeeded in arresting the movement over a large part of the area, but the seaword portion of it is still in constant motion. The speed of this movement may be judged by the fact that in April, 1897, a mass of snow 20 feet in length and 2 feet in thickness was revealed where it had been covered with sand during the preceding winter to the depth of 12 feet, the mass having been subsequently cut through by a change in the scouring movement of the wind. (See Pl. XCVII, *B*.)

The irregular deposition of the dunes has led to the formation of a number of small lakes, which, though of no geological significance, are very picturesque. They are generally bordered by a fine growth of scrubby trees, nourished by the moisture they afford, while beyond this fertile margin rise the desolate slopes of sand. (See Pl. XCVII, *A*.)

HISTORY OF THE CAPE COD SERIES.

As already indicated, the beds exhibited in this area may, so far as they have been interpreted, be provisionally divided into five groups, of

very unequal value as regards their extent or the time occupied in their formation. These groups are, in order of age, as follows:

First and lowest, the series of gravels, sands, and sandy clays which, on the basis of general aspect, are here reckoned as the equivalent of the Nashaquitsa series of Marthas Vineyard, and which, as on that island, have been subjected to a considerable amount of stressing.

Second, the dark-colored clays which are revealed at the brick pits in West Barnstable, at the base of the section on the west shore of Town Cove, at the base of the section at Highland light, and at various other points; these are known as the Barnstable series. These pits are occasionally much filled. Their position in relation to the other groups remains somewhat doubtful.

Third, the sands and clays characteristic of the Wellfleet and Truro district, found along the shore northward to Plymouth Harbor, and probably northward to Egypt or Coleman Heights, in Scituate. It is not unlikely that remnants of these beds occur in other portions of southeastern New England.

Fourth, the glacial deposits, including the morainal accumulations, the eskers, and the sand plains which lie south of the moraines.

Fifth, the beds formed since the Glacial period, consisting of dunes, spits and hooks, submarine coast shelves and shallows, and the organic deposits of swamps and marshes.

These five groups of deposits will now be considered from the point of view of their geological history.

NASHAQUITSA SERIES.

The identification of this series, as exhibited in Cape Cod, with that found at the typical locality on Marthas Vineyard, rests altogether upon the general, though close, resemblance of the physical characteristics of the deposits. In both we have the same gray measures—sands intermingled with sandy clays, which have a red or reddish hue; in both the pebbly element is scanty. In the Cape Cod exposures the red beds are more prominent than on Marthas Vineyard, but in both cases the hue is less pronounced and the clayey element less considerable than in the more ancient deposits of the Gay Head Miocene series. It seems likely that these reddish clays have in each case been derived from the washing over of the older Tertiary deposits. That such is the case on Marthas Vineyard admits of scarcely any doubt, for the reason that there the later beds contain fossils which evidently came from the erosion of the earlier series.

It is hardly to be supposed that these red clays of Cape Cod could have been derived from a field so remote as that of Gay Head. As may be seen at the last-named point, the eroded clay is not carried any distance by the tidal currents. We are, therefore, compelled to suppose that the beds in Cape Cod were derived from some areas of the Gay Head series which have been completely eroded away, or at least lowered

beneath the sea level by the wearing to which they have been subjected. The remnant of the Miocene rocks which exists in Marshfield, on the mainland to the north of Cape Cod, lies in a depression of the crystalline rocks, where it has been in a measure protected from erosion. It is eminently probable that these beds once occupied the district between Marshfield and the base of the cape. They may, indeed, have had a much greater areal extent.

The probability that the deposits of the series found at Gay Head and elsewhere on Marthas Vineyard once extended over a wide field in the cape district is made the clearer by the fact that remnants of the greensands, as is well known, occur at Marshfield, Massachusetts, north of Plymouth, and apparently also below the level of the sea in one or more points in the Monomoy group of shoals. The evidence as to the existence of the beds at the last-named point is incomplete, but it deserves a brief statement.

Among the shallows in the Monomoy area is one sometimes known as Stone Horse Shoal. This eminently curious name points to some peculiar feature in the history or structure of the place. I am told by Capt. John L. Veeder, of Woods Hole, that some years ago he was engaged in breaking up the wreck of a ship which had been for some time lying on that shoal and had become partly embedded in the sands. When the hulk rolled over it brought up a quantity of "dark sand" which contained many fragments of bones. In answer to my inquiry Captain Veeder stated that the material was like the greensands of Gay Head. It is well known that sailors are apt to class any bones as those of horses.

As to the nature of the erosion which provided the material for the Nashaquitsa series, there is little distinct evidence, and that is of a negative character. The beds on Marthas Vineyard have afforded fragments of magnetic iron ore, apparently from Cumberland, Rhode Island, and other materials which may be from the same field; but it is to be observed that the pebbles may not have been derived directly from that locality, but may have come, as is the case with much of other materials, intermediately from deposits of Tertiary or Cretaceous age. As these beds were apparently deposited not long before the advent of the last Glacial period, the question arises whether they indicate any form of ice action. To this inquiry a negative answer must in general be given. None of the pebbles are scratched or faceted; there appear to be no ice-rafted blocks; the fragments are all small, the greater part of them of quartzitic or felsitic nature, the ordinary crystalline rocks, such as are so plentifully exhibited by the glacial deposits of the last ice period, being of scant occurrence. In general the pebbles are much waterworn and affected by superficial decay, which shows that they have been long separated from their original bedding places.

The transportation of the materials of the Nashaquitsa series appears

to have been effected, in part at least, by strong and variable currents, as is shown by the stony cross bedding of the sands. At other times, and with sudden alternations, the conditions were such as allowed the deposition of fine-grained clays in these layers. It is a noteworthy feature of the formation that it contains, so far as ascertained, no indigenous fossils of a recognizable nature. This, taken in connection with the fact that on the west end of Marthas Vineyard (where alone the series is well exhibited) there are a great many organic remains of animals derived from the Tertiary rocks, goes to indicate that, though the conditions of deposition and of subsequent time favored the preservation of fossils, none were contributed to the formation by creatures living in the waters. This inorganic aspect of the beds may be due to any one of several conditions existing in this district at the time of their formation. It may have been due to the presence of a glacial sheet; but this hypothesis is less warranted than is the supposition that the deposition took place rapidly in a fresh-water basin much in the manner in which deposits are now accumulating in the basins of certain great lakes, as, for instance, in Lake Ontario near the mouth of the Genesee River. The evidence afforded by the beds is, indeed, most consistent with the view that they were thus formed in a fresh-water or estuarine body into which large and sediment-laden streams were discharged.

At first sight the supposition that this portion of the continent was the seat of considerable lakes during or about the Pliocene epoch may seem to require an excessive difference from the existing geographical conditions. It is, however, evident that the Atlantic shoreland from the Carolinas to Nova Scotia has from the beginning of the Mesozoic to the present geological time tended to develop extensive lacustrine areas. In Triassic time these areas of fresh water were numerous and large, the basins having a character and an extent comparable with those of the eastern flank of the Rocky Mountains during the Cretaceous period. A part at least of the Gay Head series, including the plant beds of the Cretaceous and a portion of the Miocene, appears to have been deposited in areas of fresh water. It is not necessary to suppose that these areas of fresh water were completely separated from the sea; they may have been estuarine in their nature, much as are the sounds of North Carolina and other portions of the southern coast of the United States.

The question arises as to the original extension of the deposits of the Nashaquitsa series. As yet they have been definitely observed only on Marthas Vineyard, in the islands of the Elizabeth Archipelago, and in the area we are now considering. It is likely, however, that beds of equivalent age exist in Block, Fishers, and Long islands. Deposits of perhaps the same age may exist farther to the south, though until fossils are found in the Massachusetts area there will be no sufficient means of fixing the age. The fact that these beds are found scattered over a considerable area in the manner before noted indicates

A. SECTION OF PART OF TRURO SERIES ON NORTH SIDE OF PAMET RIVER, NEAR BRIDGE.

B. VALLEY EXCAVATED IN TRURO SERIES, CHILTONVILLE, PLYMOUTH.

that they were at one time extensive. The height they now occupy, notwithstanding the considerable erosion to which they have been subjected, shows that they must have been formed when the level of the sea was much higher than at present. Thus on Marthas Vineyard they lie at not less than 200 feet above the tide, and their upper surface has shared in the erosion which has served to develop an old and deeply incised topography on the area. It is, indeed, necessary to assume that the upper surface of the deposit originally lay at a far higher level, perhaps 100 feet or more above its present plane.

As to the dislocation of the beds, this seems to have occurred before the erosion which formed the valleys in which lie the bays and sounds that separate the known location of the deposits. The time of the dislocation can not be more definitely stated than that it was after a part, at least, of the Pliocene had been deposited and before the deposition of the Barnstable clays or the Tisbury beds, which apparently lie above them. The interval between these stages was evidently of considerable duration, even in the geological sense of the word, for it included not only the time occupied in the folding but also the period required for a considerable erosion of the beds.

Concerning the extent of the dislocations which have affected the Nashaquitsa series, it may be said that it was much less intense and general than that which is recorded in the Gay Head section. In the area occupied by the last-named group of strata, about 30 square miles in extent, the average dip of the beds is about 45°, and no part of the layers, so far as seen, remains in a horizontal attitude. In the case of the Nashaquitsa series the greater portion of the Marthas Vineyard area is but little dislocated, and on Cape Cod the average departure from the original horizontal attitude is apparently only a little greater than it is on the Vineyard, probably not averaging more than 10° of declivity.

The foregoing considerations justify the supposition that the Nashaquitsa series originally occupied an area along this portion of the shore of the continent; they warrant also the belief that this area was, after a slight though distinct dislocation, carved into an extended topographical relief and that the surface of its more salient points was considerably lowered in the process. We have to suppose that this carving was, in the main at least, due to river action, though the valleys may have been affected by marine agencies after they were lowered beneath the plane of the sea.

THE BARNSTABLE SERIES.

After the formation of the topography cut in the Nashaquitsa series had been effected the district was again depressed beneath the sea. The downward movement certainly brought the coast line at least 100 feet above its present level, for the Barnstable clays attain the elevation of 60 feet above tide, and the Tisbury clays, their probable equiva-

lent, rise to about 90 feet. As these clays, particularly those of the Barnstable area, have the character which belongs to deposits formed at some distance from the shore line, it is likely that the down-sinking was to a much greater depth than is here indicated.

Clays of the same general nature as those of the Barnstable series occur along the shore to the eastward as far as Chatham, though the best exposures known to me are those on the present marine escarpment and in the clay pits at Barnstable; there they seem everywhere to underlie the glacial deposits, being usually separated from them by a variable thickness of apparently pure glacial sands and clays.

It is not unlikely that some of the brick clays lying farther northward and westward on the mainland, as well as other deposits in Harwich, are of the same age as those of the Barnstable series, but their discrimination is difficult and has not yet been effected for the reason that they do not apparently differ in any distinct way from those of later date and of undoubted glacial origin.

The gravels in the clays of the Barnstable series are known to me only by the reports of those who have penetrated the beds in sinking wells. They are described as composed of small pebbles, mingled or coated with iron oxide.

The Barnstable beds, as has already been suggested, may be the equivalent of the Tisbury beds of Marthas Vineyard. The evidence of the identity of age is, it must be confessed, not very strong. It rests altogether on the fact that in both cases clay beds not greatly disturbed by the mountain-building forces rest upon the disturbed Gay Head series, and that they have both been elevated to a considerable height and carved by erosive agents. To suppose that the two series are of diverse age would require the assumption that there had been one more cycle of erosion, subsidence, and elevation in the Pleistocene period, which is already overcrowded with actions of this nature that I have been compelled to postulate in order to explain the geological structure of the district.

As against the supposition of the identity of age of the two sets of beds, it may be said that the Tisbury series forms a distinct, though much eroded, bench on the north side of the island of Marthas Vineyard. There is no evidence that they ever had a very wide lateral extent. The beds are mottled yellow and bluish clays and sands, with occasional bowlders of small size, which may possibly have been ice-rafted to their present positions. The materials of the strata have apparently been derived from the erosion of the Cretaceous and Tertiary beds of the dislocated area against which they lie. It seems quite possible that with the advance of our knowledge of this district it will be found that the Barnstable beds, which appear to have been formed in deep water in an offshore position, are not to be regarded as in age the equivalents of the Tisbury beds, which were evidently formed nearer the shore and in a shallower depth.

A. STREAM CHANNEL CUT IN CONTORTED CLAYS, NORTH WARWICK STATION.

B. HILL NEAR CHATHAMPORT; TRURO SERIES, DRUMLOID OUTLINE.

It is to be understood that evidence of a diversity in age of the glacial clays and of the beds here referred to as related to the Barnstable series is not perfectly clear. I see no reason to doubt that the formation of the deposits which lie beneath the cape and the region to the northward as far as Plymouth Harbor clearly antedate the last ice epoch, but some of the clay beds of the cape district may have been deposited during the time when the ice work was in progress. It should also be noted that even if the glacial origin of the Barnstable series should be proved, the evidence is still to the effect that the ice action was not that of the last advance, but an epoch separated from it by events which indicate the lapse of a great interval of time. This will be more evident in the sequel.

TRURO SERIES.

The characteristic Truro series is even more generally concealed than are the beds which lie beneath along the eastern shore from Wellfleet to Highland light. They are, it is true, revealed in the wasting cliffs, but the amount both of slipping and of loose débris is so great that it is not possible to determine further the character of the section than that it is composed of a hundred feet or more of fine, gray, micaceous sands and sandy clays in frequently alternating beds. These beds apparently contain no fragments of compound rocks; the only pebbles they carry—and these are small and of infrequent occurrence—are composed of white quartz. The beds appear to be somewhat disturbed, but the irregular sliding of the cliff as it is undercut by the sea makes this apparent evidence of orogenic stress untrustworthy.

At only two places has it as yet proved possible clearly to ascertain the true attitude of the beds in the Truro series. One of these is a pit whence clay for hardening roads has been taken. It is on the north side of Pamet River, immediately south of the road, and a few hundred feet from the bridge over that tidal stream. The section is as shown in Pl. XCVIII, *A*, and in fig. 90, p. 534. The materials consist of alternating clays and sands, such as are shown on the cliff at Highland light, even bedded and quite without pebbly matter except bits of rounded quartz. They lie at an angle of about 18°, dipping northwestward. There is a thin layer of pebbly drift on the top of the section. (See Pl. C.)

Another exhibition of these beds is in a clay pit 200 or 300 feet north of South Wellfleet station. Here the beds are at higher angles than in the section near Pamet River bridge; in part the slopes are of 30° or more. The bedding, indeed, seems to be crushed as it is at certain points on Marthas Vineyard. Here, as in the last-named section, there is a thin overlay of pebbly washed drift, with small rounded bowlderets.

It should be noted that the sections above described were obtained at the only points where the attitudes of the Truro series could be clearly discerned. Taken in connection with what has been observed on the cliff shore and in a considerable number of obscure artificial

exposures, there is evident reason for believing that the strata of this series are generally dislocated much as are the beds of Tertiary age on Marthas Vineyard.

It appears to me unreasonable to suppose that the steep dips of the beds of the Truro series are due either to cross bedding or to glacial thrusting. The sections examined are sufficiently extensive to reveal the true structure. They show nothing to arouse the suspicion that these slopes are due to deposition on the construction point of the stratum. As for the thrusting, there is, as is elsewhere noted, no good reason to believe that the glacier ever eroded this surface. If it did so, its action was not vigorous enough to have eroded the delicately molded pre-Glacial topography.

The feature which most distinctly separates the surface aspect of the Truro sands from that of the morainal aprons is their slope. This is not, as in the sand plains of Barnstable and elsewhere, toward the open sea on the east, but distinctly toward the bay on the west. The surface is, it is true, to a certain extent encumbered by the waste left upon it in the last advance of the ice; but making allowance for this coating, it is quite evident that the slope, instead of being outward from the ice front, was inward toward the face of the glacier. If, indeed, the deposit is to be regarded as a sand plain, it will have to be assumed that the ice lay outside of the cape, discharging its waste westward toward the bay, a view which is manifestly inconsistent with all we know of the distribution of the glacial envelope on this part of the shore.

Taking no account of the deformations of the surface in Truro and Wellfleet, which have been brought about by the small amount of glacial waste which the area bears, the westerly slope is clearly indicated either to the eye of the observer in the field or by the inspection of the topographic map, where the contours are seen to lower as we pass from the outer or eastern to the inner or western side of the area.

As we pass from the eminently characteristic surface of the sand deposits of Truro and Wellfleet toward the southern and western parts of the cape, the glacial deposits thicken and become more irregular, until in Orleans the Truro sands are to a great extent concealed by this drift. Nevertheless, beds of the same general nature are noticeable at most points where a natural or artificial section is carried to any considerable depth in all the area as far west as Yarmouth. They are particularly well shown in Dennis and Harwich, and are also revealed in the southern parts of Brewster and the northern portion of Harwich. It is here, as in the typical localities of the series, quite evident that the surface was deeply incised by the action of streams before the last invasion of the ice, which served to encumber and at times efface the preexisting valleys, though the erosive action which conveyed this waste was not sufficiently intense to cut away this rather delicately molded topography. Throughout the area in which these

A. TALUS SLOPE, HIGHLAND LIGHT.

B. CONTORTED TRURO CLAYS AND GRAVELS NEAR CHATHAMPORT.

ancient sands are traceable they generally rise on the crests of the ridges which they occupy to the height of about 100 feet above the level of the sea. It seems likely that while glacial erosion, mainly if not altogether due to streams from beneath the ice, may have cut down these crests to a certain amount, the extent of this wearing has probably been not more than a few feet.

The original extent of these Truro sands is, on account of the erosion to which they have been subjected, not clearly determinable. It seems, however, to have been great, as will be seen from the following notes concerning the distribution of beds apparently of that age which occur in a fragmentary manner in and about Cape Cod. In the western part of the cape there is reason to suspect that deposits of this age underlie the ridge of the Falmouth moraine. Exposures of yellow sands are shown at a number of points on the western face of the moraine in positions which indicate that they are portions of a large area which extends beneath this mass and rises to a considerable height beneath it. On the island of Naushon, the northernmost of the islands of the Elizabeth Archipelago, orange-colored sands with characteristic absence of coarse waste underlie nearly, if not quite, all of the area and rise to the usual height of about 100 feet. Southward throughout this group of islands to Penikese beds of this character and presumably of the same age are seen here and there, evidently lying in the Nashaquitsa series. On Marthas Vineyard the series is less well shown, yet it is tolerably well indicated on the northern side of the island at Copoggan Head (misnamed on the maps Cape Higgon), as well as at other points between Menemsha Creek and West Chop. They are also seen in the retreating escarpments of East Chop and West Chop and the sea face at Cottage City.

Beneath the great plain of Marthas Vineyard, the upper portion of which is clearly of the character proper to morainal aprons, there is revealed by occasional wells extending to the depth of 70 to 90 feet a deposit of yellow sands with no large pebbles, which appears to belong to this group. Here we have to suppose that the beds had been worn down by marine or other action to a level somewhat below that which they occupy elsewhere and then sheeted over with the deposits formed during the last advance of the ice. In the valleys of Tisbury and Tiasquan rivers, in the central part of Marthas Vineyard, and at Gay Head there are traces of the same sands, which are scantily revealed and only discriminable from the deposits of the Nashaquitsa series by the characteristic yellow hue.

West of the base of the cape, along the southern shore of Massachusetts, deposits which may be compared with those of the Truro series are not clearly disclosed and may not exist, though the search for them has not been carried so far as to make their absence certain. In Rhode Island, as has been suggested to me by my colleague, Mr. J. B. Woodworth, beds of this age may underlie the Charleston moraine, where,

as remarked by the late J. D. Dana, stratified sands appear to underlie the morainal deposits. The scanty outcrops of these beds in their appearance warrants the supposition that the formation has the same general character that it exhibits in the localities before described.

North of Cape Cod, along the shores of Massachusetts Bay, the Truro sands, overlain by distinct glacial deposits, are abundantly exhibited. On the shore of southern Plymouth, from point to point, they form the marine escarpment. (See Pl. CIV.) In the high ridge of Manomet Hill they probably attain the height of 250 feet or more above the level of the sea. The erratics, which are so abundant on the ridge and which give it the character of a moraine, form only a relatively thin coating on the summit of a pre-Glacially-formed ridge, resulting from extended subaerial erosion of the inferior sands. (See fig. 92, p. 555.)

North of Plymouth the curious table-land known as Egypt Heights, in the southern part of Scituate, appears to be composed of beds in character quite like those at Truro. The general form of this curious deposit of sand can best be explained by the supposition that it is the remnant of a large area, and not a local deposit accumulated during the last Glacial epoch. This view is supported by the general character of the material, which is much the same as that of the Truro section, though it is more deeply covered with recent glacial waste. Scattered patches of the same decayed sands continue to the northward as far as Boston Harbor. In that basin, mostly below the level of the sea, a thick deposit of sands clearly antedating the last ice epoch has been revealed by artificial sections, as in the tunnel for the Moon Island sewer, and particularly in a well boring made on Deer Island. At the last-named locality a thickness of 300 feet was passed through, the beds being in general character like those before described, except that the oxidation was less complete than at the other parts. The evidence goes to show that here, as elsewhere, this section of decayed sands with few pebbles is immediately, though discordantly, overlain by the bowldery drift. North of this point on the shore I am not aware of any sands which may be referred even conjecturally to the Truro series.

In the district of southeastern Massachusetts, remote from the shore, I am aware of but one locality where deposits of much-oxidized sands having the general character of those before described are clearly revealed. This is at Prospect Hill, in the southern part of the town of Raynham and the western part of Taunton. At this place we find an irregular ridge, composed mainly of sands with a few pebbly beds, capped in part by a layer of bowldery nature, which gives the mass something of the aspect of a moraine. Some years ago I came to the conclusion that the greater part of this ridge represented a much-eroded deposit, which was formed before the last ice advance and which had been scantily affected by a morainal accumulation made

TRURO SERIES AND GLACIAL BEDS, HIGHLAND LIGHT.

in that stage of the Glacial period. It now seems most reasonable to regard this as a remnant of the deposits of the Truro series.[1]

It is probable that many other deposits of well-oxidized sands which exist in southern New England will eventually be found to represent the same epochs of Pleistocene time as those above catalogued. At present they are naturally, and it may be inextricably, confused with the accumulations of washed drift which were so plentifully formed in front of the ice during the later advances of the glacier. As will be further noted in the study of the glacial deposits of Cape Cod, the Truro series may possibly be but the outer remnant of a broad sheet of shore sands formed during the earlier epochs of the Glacial period, when the margin of the ice lay at some distance north of the present shore, and that this moraine accumulation passed into other types of glacial waste as it approached the ice front.

The facts before noted make it probable that at some time before the advent of the ice of the last Glacial period in the region about Cape Cod the surface of the land was at a much lower level than it is now—at least 100 feet lower—and that at that time an extensive sheet of water-borne sands was deposited on the sea bottom. It seems necessary to suppose that this sheet was laid down as a tolerably continuous outward-sloping formation, such as is now found in the continental shelf along the Atlantic coast. It certainly could not have accumulated in the patches and ridges in which it now appears. We can not, for instance, suppose that the crest which forms the foundation of the Elizabeth Islands, and which rises about 150 feet above the present level of the sea floor, or that of the Truro Plateau, which attains a like or greater height above the bottom of Cape Cod Bay, was formed as we now find it. We are forced to assume that these evident remnants of erosive work were originally parts of a widespread deposit, by far the greater part of which has been swept away.

The time of the erosion of the Truro sands, which reduced the area of the formation to the few remnants we now find, clearly antedated the last advances of the continental glacier. This is indicated by the facts that the position of the remnants is that which they would occupy if they were left by water erosion, but not such as would exist if the wearing had been effected by ice, and that the preexisting rather delicate topography, such as would have been carved by stream action, was not destroyed by the glacial erosion. In illustration of the first of these points it may be said that the ridge of the Elizabeth Islands is precisely such as would be brought about if it had been a divide between the supposed rivers of Buzzards Bay and Vineyard Sound, but in no way could it well be explained by glacial or marine erosion. As for the second, the many pre-Glacial channels on the Truro-Wellfleet plains show how even delicately sculptured valleys were not completely

[1] Since this report was written beds apparently the equivalents of the Truro series have been found by the writer at a number of points in southeastern New England.

defaced by the wearing influence of the glacier which came upon them in its marginal and attenuated form, if indeed they were ever actually beneath the ice.

As for the time when the erosion of the Truro sands was effected, we may confidently place it in the later part of the long interval which is partly, at least, recorded in the well-developed subaerial topography which was made on Marthas Vineyard after the cessation of the dislocation of the underlying beds and before the advent of the ice of the last Glacial epoch. As before remarked, this interval was long, for the work done during it was vast. It is clear that the Truro beds were formed after this topography was pretty well completed, for beds referable to the age lie partly in the valleys due to the erosion in question. It is thus evident that the greater part of the erosion of these later sands came after the shape of the Vineyard topography had been in large part determined, but probably before the valleys thereof had attained anything like the present development. (See Pls. CII, CIII.)

The reduction to a plain of the Truro sands was probably in part effected by the action of the sea. As may be noted along the shores where these beds are subjected to the action of the waves and marine currents, the beds wear away with exceeding rapidity. It may, however, have been in considerable part accomplished by ordinary stream action, as is shown by the persistence of many ancient valleys in those parts of the cape district underlain by these deposits. It is, however, difficult to believe that this stream erosion took place under the present conditions of climate and geography, for the reason that the beds of these ancient water ways are no longer occupied by streams, except, perhaps, on the rare occasions when, on a frozen earth, melted snow or rain is deprived of its usual exit by percolating into the porous underlying sands. The absence of water in these channels is probably to be attributed in part to the fact that they have been greatly shortened by the cutting away of their headwaters, so that the water now flowing seaward in their drainage is less in amount than of old, being no longer more than can pass through the interstices of the sands, through which it more readily finds a passage because the way to the sea is not so long as of old. It is probable, however, that the amount of the rainfall has in geologically modern times diminished in this region, as elsewhere on this and other continents, so that the capillary channels are able to afford storage and passage to all the precipitation. It may be observed that in times of any great rainfall sandy plains occasionally for a short time develop superficial streams, the water quickly ceasing to flow when the precipitation stops.

The rate of the erosion of the Truro beds wherever they are assailed by either marine or fluviatile agents is made the greater by the fact that the beds are destitute of coarse débris, which, in the case of the till, brings about the formation of a more or less effective revetment on the erosion face that hinders the action of waves or currents.

A. MOON POND ESCARPMENT, FACING PROVINCETOWN SPIT.

B. BEHEADED WATERLESS VALLEY JUST SOUTH OF HIGHLAND LIGHT.

Moreover, the very lean nature of the soil causes the growth of vegetation to be slight in amount, so that the protection of this sort which is usually so important is scanty. Thus the wearing rate on this group of deposits is likely to be very much greater than it is on such beds as form the Tertiary strata of Marthas Vineyard, frail as the latter appear to be. (See Pl. XCVIII.)

The most important indication pointing to the origin of these Truro sands is the apparently entire absence of fossils in the section. In the extensive outcrops which I have inspected no trace of organic matter has appeared. It seems clear that the beds were laid down under conditions which were peculiarly unfavorable for the inclusion of organic remains, or that such remains were subjected to some process which utterly removed them. Although, as before noted, these beds are considerably oxidized, it can not well be believed that fossils once present have been utterly destroyed. The Tertiary sands of Virginia and elsewhere are equally affected by decay, yet the mulluscan remains are fairly well preserved. Assuming, then, that these beds were originally formed without organic remains, the probability is fairly established that their materials were brought into the sea by glacial action. In no other way does it seem possible to account for the formation and deposition of such a mass in a marine or lacustrine area. It is to be said that this view has its difficulties, among which we may reckon the apparent absence, as before noted, of all ice-rafted blocks in the beds and the lack of clay in the greater part of the section.

Taken in connection with the seemingly nonfossiliferous clays of the Barnstable series, the Truro beds may perhaps be regarded as a stage in one of the several cycles of a glacial period. It is a well-recognized fact that the glacial flour or fine débris, which in the ordinary course of glaciation constitutes the larger part of the detritus that is formed, is normally carried much farther away from the front of the sheet than the sand, and that this in time goes farther than the pebbly matter. We may thus reckon that the Barnstable clays are the outer or relatively remote accumulations of an ordinary glacier, and that the Truro sands were laid down when the ice front was nearer the present shore line. If this view be accepted, we must then suppose that in the ice epoch which brought about the formation of this series—probably not the last Glacial epoch—the glacial sheet did not quite attain to this field, and that the land lay at a lower level than it does at present. As is clearly indicated by the extensive erosion which followed this period of deposition—erosion in which the glacier appears to have had no part—the time intervening between the formation of the Truro beds and the advance of the ice sheet which deposited the till, moraines, kames, etc., of the district must have been great. It was assuredly many times as great as that which has elapsed since the last of the ice sheets left the field.

Although the matter has been before stated in a fragmentary manner,

it may be well again to call attention to the accumulation of evidence which exists in this field going to show the very great length of the time which has elapsed since the close of the Pliocene. In this interval there were evidently three distinct periods of erosion, each of long duration, and an equal or greater number of widely varying changes in the position of the land in relation to the sea. As measured against the geological work which was done in these periods, that brought about since the close of the last ice advance is relatively of little account, being limited to slight changes of level and to a small amount of marine cutting, the subaerial wearing being quite insignificant, perhaps not the one-hundredth part of what was done in the earlier stages of the so-called post-Tertiary. It thus seems that, basing the measure on a vaguely assumed rate in the alteration of organic forms, we have most likely much underestimated the duration of this division of the earth's history.

CONDITION OF THE DISTRICT AT THE BEGINNING OF THE LAST GLACIAL EPOCH.

The conditions of height and shape of the land in this area immediately before the advent of the ice of the last Glacial epoch appear to be approximately determinable. It is tolerably evident that the land lay at a higher level in relation to the plane of the ocean than it does at present. This is indicated by the existence of the flooded drainage basins, which have been already in part described. These drowned valleys include not only the greater basins of Cape Cod Bay, Nantucket and Vineyard sounds, and Buzzards Bay, but many of the divisions or branches of these wide valleys where the streams tributary to the effaced rivers now enter the sea. Thus, on the islands of the south as well as on the mainland all the valleys which are now or have been in former times the seats of streams are flooded at their mouths.

On the north shore of Cape Cod we find a number of pre-Glacial channels which slope toward the bay of that name, and which evidently were at the time of their excavation the beds of streams discharging into a river that flowed northwardly to the shore line, which was farther out seaward than at present. These old valleys may be traced from Duxbury to the northern part of Truro. They point toward the central portion of the submerged trough in a normal and most suggestive manner. On the body of the cape these channels are generally much occluded by the deposits of glacial drift. They are to a considerable extent deformed by the scouring action of the streams which flowed beneath the ice sheet while it lay over the country.

The first of these channels of Cape Cod to be noted is that of Monument River, which now is a tidal stream discharging into Buzzards Bay. As it is clogged at its northern end by drift, it appears as a tributary of the ancient stream which occupied the valley of Buzzards

A. TOPOGRAPHY CHARACTERISTIC OF THE TRURO SERIES; VALLEY OBSTRUCTED BY GLACIAL DRIFT.

B. BLUFFS OF TRURO SERIES, PAMET RIVER VALLEY.

Bay. The form of the trough, which distinctly widens to the northward, suggests that it originally flowed into Cape Cod Bay, and that the ridge which originally parted it from the waters of the south was cut through by a torrent which flowed through this depression in the time when the basin to the north was occupied by the glacier. Eastward along the north shore of Yarmouth the streams appear to have been short and to have drained north and south from the highland now covered by the moraine, and which is locally known as the "Backbone of the Cape." The valleys of these streams draining northward are now but faintly traceable in the confusion of the morainal drift. On the south side of the ridge the valleys are to a great extent lowered beneath the frontal aprons of stratified materials, yet they may be indistinctly and in a general way traced by the depression in which lie the lakes and the streams which drain them.

At Bass River we have another instance in which a pre-Glacial valley (or valleys) has been enlarged and deepened by a current from the glacier. At this point there seems originally to have been two streams, one flowing northward, the other southward. The subglacial stream cut through the ridge between them, converting the trough into a broad way, which practically divides the cape, so that a trifling expenditure would suffice to make a water way from the north to the south side of the peninsula.

East of Bass River as far as Orleans the central ridge of the cape continues; the valleys become less and less blocked with till and morainal waste. This is especially the case on the north side, where the valleys in Dennis and Brewster channels, with rather obscure digitations pointing toward Cape Cod Bay, may be well traced. Beyond Orleans the ancient central watershed disappears, the sea having eaten into it from the east, and the larger valleys usually run across the width of the peninsula. This feature is best shown at Pamet River (see Pl. CIII), where one of these depressions appears—after the manner of the valleys of Bass River and Monument River—to have been depressed and widened by a glacial stream until it completely divides the peninsula, so that there is only a sand beach at the outer side to unite the farther part of the cape with the body of the area. There are, however, many lesser valleys which slope to the northward and which seem essentially river ways, though they are no longer occupied by streams. These troughs appear to be beheaded at their upper or outer ends, their conditions suggesting that their headwaters lay in the lost territory which has disappeared by recent marine erosion (see Pl. CII). In the account of the Truro beds it has been suggested that the former presence of streams on these now dry valleys may be accounted for by the above-suggested diminution of their drainage area, or perhaps in part by the diminished rainfall which appears generally to have attended the disappearance of the glacial sheet and which may have been the cause of its shrinking.

It is evident that the shape and size of Cape Cod shortly before the time when the glacier came upon it differed greatly from what we now find. In place of the narrow peninsula, in form like the flexed arm of a man, was a broad salient which extended as a connected land to some distance beyond the outer margins of Nantucket and Marthas Vineyard. At this stage the sea level probably stood about 200 feet lower than it does at present. During the time when the ice lay over the district it was depressed to a level at least 100 feet below where it now stands. This permitted the formation of the great sand plains of Marthas Vineyard, Nantucket, and the cape. When the ice departed the land in part resumed its old height, rising a little above its present elevation, and then sank, as is shown by the submerged forests which occur from point to point along the shores.

GLACIAL HISTORY OF THE DISTRICT.

It has already been noted that the deposits contained in the strata from the Miocene to the Truro series, inclusive, suggest the existence of glacial action in this part of the world at various times since the middle Tertiary; but unless the lower Pliocene beds of Gay Head attest the actual presence of ice, there is no reason to believe that it ever rested upon this field until the last epoch. Even in that time the sojourn of the glacier was evidently brief and the work which it did of relatively slight structural or geographical importance. It has already been noted that the general character of the surface had been determined by pre-Glacial conditions The valleys and ridges existed in general about where we now find them, only now they are to a great extent filled with glacial waste.

It seems pretty clear that immediately before the advent of the glacier the surface of the cape was carved into a topography such as is likely to be formed on clays and sands by the headwaters of streams. The valleys were rather deep and steep-sided. Where the clays come to the surface these valleys appear to have had something of the sharpness of the "bad-lands" topography of the western country. This is shown by the indented character of the old surface of the Nashaquitsa beds on Marthas Vineyard, where it is revealed in the coast sections. It is indicated on Cape Cod by the sharp ridges of clay, the so-called "pounds," which occasionally appear at the surface, projecting through the thin envelope of drift. The generally slight value of glacial erosion in this district is best shown on the island of Marthas Vineyard, where, as noted in previous reports, the wearing has been so slight as to leave the pre-Glacial topography essentially undisturbed except by the filling of the valleys with detritus.

On Cape Cod the actual erosion work is little if at all greater than on the islands of the south except in the case of the valleys which were cut through by the streams flowing from beneath the glacier or

A. SHORE BLUFF SOUTH OF SHIP POND, PLYMOUTH, SHOWING TRURO SERIES DIPPING STEEPLY NORTHWARD.

B. SHORE BLUFF SOUTH OF SHIP POND, PLYMOUTH, SHOWING TRURO SERIES FOLDED AND FAULTED.

under the roof of ice. Of these the most characteristic examples are Monument and Bass rivers. The channel of Pamet River is perhaps another example of the same nature.

There seems no evident reason why the subglacial streams which were on their way to the open water of the ocean should have climbed the ridge of the cape on the south in place of turning directly to the east around its extremity, which was then some distance south of the site of Provincetown. In view of this departure from the most direct way of escape, it may be suggested that as the ice fell back to the northward it may for a time have inclosed a lake between its retreating face and the concave north shore of the cape. In this case breaches would naturally have been formed to permit the discharge of this water from the melting ice through to the sound on the south. It is, however, not certain that any part of the cape was above the level of the sea at the time when the retreat of the ice took place. The only strong point in favor of the view that these channels were glacial stream beds is the fact that they are cut down to the sea level practically throughout their whole length, and that their forms indicate the passage of a current from the northward, and in the case of Monument River there is a considerable area of stratified sands near its mouth, on Buzzards Bay, which may well be taken as the delta formed where the current poured into that basin.

DIRECTION OF THE ICE MOVEMENT.

As the rocks of Cape Cod and the neighboring parts of southeastern Massachusetts are not of a nature to receive glacial scratches or groovings, the only indications of the direction of the ice flow are those afforded by the positions of frontal moraines and the direction in which erratics have been transported. It should be said that the moraines in this section present such discrepant evidence that conclusions drawn from their positions are not trustworthy. The transported blocks, therefore, furnish our only information, and this is in the main unsatisfactory.

In the western section of the cape, from Monument River to Orleans, the common petrographic elements of the moraine and till are granitites and the dike stones associated therewith, such as are found on the mainland. As these rocks occur along the shore from the parallel of Plymouth to Cape Ann, and may extend an indefinite distance eastward along the sea bottom, no precise evidence as to the course of the ice is to be obtained from these fragments. Eastward from the base of the cape there appears to be a constant increase in the amount of rocks of more evidently volcanic origin, such as are found sparsely about Cohasset and along the north shore of Massachusetts Bay. The deposits of this nature on the mainland are rather too limited to have afforded the large quantity of waste that appears in the cape. It seems likely that they have been derived from beds which lie beneath the sea.

So far as this evidence goes, it seems to show that the direction of the glacial movement on Cape Cod probably did not depart from the general trend indicated by the scratches observed at the nearest points on the mainland, or between north and north 30° west.

ENERGY OF THE ICE MOVEMENT.

As has been already noted, the energy of the glacial erosion in this district appears to have been but slight. It did not suffice to wear away a rather delicate antecedent topography. On the western part of the cape the transporting power of the ice was sufficient to carry a great number of erratics, many of which are of large size, thousands of blocks each containing from 100 to 300 cubic feet being exposed on the surface of the principal moraine. In the period of its greatest extension the ice apparently passed over the ridge of the cape as far east as Orleans, crossed the valley of Nantucket Sound, and deposited on the island of Nantucket the slight morainal masses which there exist, and which perhaps mark the extreme advance of the ice on this part of the coast.

North of Orleans and thence to the end of the cape there is no distinct morainal accumulation, but occasional wide heaps of drift and the clogging of the pre-Glacial valleys show that the surface was traversed by the streams pouring forth from the glacier. The general lack of erratics other than those which may have been ice rafted, or of any accumulation which can be classed as a moraine, or even as distinct till, shows that at this point the glacier, if it actually lay on the surface, was probably so weak and thin that it had no longer any considerable abrading or transporting capacity. The conditions here resemble those found on the southern part of the highland of Marthas Vineyard, where large portions of the surface are nearly driftless.

Although the carrying power of the ice as marked by the accumulations of erratics was not great, that of the streams which flowed from beneath the glacial sheet was excelled, so far as I have found in New England, only by those which deposited the great sand plain of Marthas Vineyard. As to the extent of the deposit, that of the cape is unexampled elsewhere in southern New England. The area is probably not less than 120 square miles, but the thickness appears to be much less than that of the like mass in the island to the south.

GLACIAL DEPOSITS.

The deposits due to the direct action of the glacial sheet are the till, the moraines, and the washed drift accumulated in the eskers and the sand plains.

The till deposits of this district are neither extensive nor characteristic. Along the north shore especially the areas are immediately underlain by the Barnstable clays. The coating is evident, but very

irregular; in places it is so thick as to resemble a morainal accumulation; at others considerable tracts appear to be quite without the deposit. Toward the eastern extremity of the cape the coating becomes thinner and less recognizable. Angular erratics are rare in the section beyond Yarmouth, and beyond Orleans few erratics greater in size than those termed by Chamberlin "bowlderets" are found, and these appear to have been conveyed by floating ice.

Between Orleans and the northern portion of Truro the till becomes a mere confused mass of the materials of the local beds over which the ice has passed in its movement, with occasional erratics of moderate size which were brought from a distance. It is difficult to recognize it as a distinct element in the sections, for it is essentially wanting over large areas of the surface.

The morainal deposits of the Cape Cod district, though less extensive than those found in the central parts of the continent, are by far the most characteristic in New England, presenting phenomena which are in many ways peculiar. They deserve, therefore, the detailed consideration that will here be given them.

The moraines of southeastern Massachusetts are singularly distributed. In southern New England they lie usually in lines which are evidently almost at right angles to the direction of the ice motion, and variations from this position can usually be explained by the topography of the bed rocks over which the ice moved; but in the cape district, including the neighboring islands and the mainland, the ridges are set at curious angles to one another. There the following directions may be noted:

On the mainland the Plymouth moraine, which extends in a general southerly direction from near the harbor of that name, appears at first sight to be the largest, and is perhaps the most continuous, deposit of the kind in New England. In its northern portion, at least in Manomet Hill, it is underlain by the Truro beds, which arrangement has given a false impression as to the depth of the glacial waste. With some interruptions it is continued southward to Monument River, at the base of the cape, in an approximately meridional axis as far as Woods Hole, and thence, deflecting westward about 30°, it is continued down the Elizabeth Islands nearly to their southern extremity.

On Marthas Vineyard there are two evident morainal belts parallel to that of Falmouth—one on the north side of the island, which is characteristically developed; the other in the central section, which is faintly shown, but can be traced by scattered patches of bowlders. On Nantucket there is a small area of moraine on what is known as Sauls Hills, but the axis of the accumulation is not well indicated; it appears to be in a general east-west direction.

On Cape Cod, occupying, as before noted, the high land formed by the ancient divide of the tilted series of beds, there is a morainal mass extending in an east-west direction from Monument River to the

eastern part of the town of Brewster; it may be regarded as continued in a slight form into the western part of Orleans. It is to be observed that this ridge lies at nearly a right angle to the course of the Falmouth moraine, with which it, in effect, coalesces at its western end. Although the general direction of this moraine is east and west, its shape is somewhat concentric, the curve being toward the south, the most southerly part thereof being near Bass River. It is thus evident that there are two distinct alignments of ice-morainal ridges in this district; the one, that which is clearest in its direction, being meridional in the Plymouth ridge, but deflected to a northeast-southwest course in its more southern elements; the other having essentially an east-west course.

So far the diverse positions of the moraines in the Cape Cod district have been explained by the theory of lobations in the front of the glacier, portions of the ice sheet pushing out in broad tongues, each of which made its frontal wall. These walls formed successively, intersecting one another in much the same manner as that of Falmouth intersects that of the cape. While in nowise doubting the adequacy of this explanation as applied to the interior districts of this country by Chamberlain and others, I am compelled to question its applicability to the field now under consideration, for the following reasons:

The Cape Cod district comprises no strong topographical features which could have caused the ice sheet to flow in the directions which would have to be postulated if these several moraines were formed at right angles to the axis of movement. It is unreasonable to suppose that, while the general course of the ice in the neighboring interior district was from northwest to southeast, it should have been directly southward in Massachusetts and Cape Cod bays and directly to the east in the region about Plymouth. On the contrary, the natural conditions, so far as they can be ascertained, would have led the ice in these bays to flow eastward toward the open sea and not southward toward the high ridge of the cape. I have therefore been compelled to seek another explanation of the axial order of these moraines, and have framed what seems a plausible hypothesis to account for this order without having recourse to the theory of lobation of the ice front, which has its difficulties, as just noted. This hypothesis is, in effect, that the moraines of the Cape Cod district are not of the ordinary type, but belong to a hitherto unrecognized group of hilltop drift accumulations, which, though essentially morainal in their nature, were formed under peculiar conditions, rendering them of slight value as indices of the direction of the ice movement.

It has already been incidentally noted that certain parts of the several moraines described in this report rest upon antecedently formed ridges, which, in effect, were the ancient drainage divides of the country. Let us now examine the several deposits to determine how far this peculiar character is possessed by the moraines in general. Begin-

ning with the northernmost of these ridges, Manomet Hill, in Plymouth, it will be found that the elevation is composed mainly of stratified sands, apparently of the Truro series, as has been recently shown by the excavations made in lowering the grade of the State road, which traverses the northern end of the ridge. In other words, the mass of the ridge is of pre-Glacial age, and was probably a divide between the headwaters of the Buzzards Bay river and that which drained the basin of Cape Cod Bay. So far as can be ascertained, the same underlay of sands extends beneath the rather indistinct morainal ridge that continues the Manomet Hill deposit southward to the base of the cape. These sands are not clearly seen, in sections, to pass beneath the morainal belt, but are exposed near by in positions which make it tolerably certain that they must underlie it in the manner of a pedestal, as in the case farther north. (See fig. 92.)

The Falmouth continuation of the Plymouth ridge is by far the longest and most united mass of morainal material yet noted in New England. It extends from Monument River to Woods Hole without any breach in its distinct wall, which rises to a height of from 100 to 200 feet above the sea level throughout its length of about 18 miles.

FIG. 92.—Diagrammatic section of Manomet Hill, Plymouth. A, glacial deposits; B, observed Truro deposits, 100 feet; C, supposed Truro deposits, 150 feet; D, sands and clays of unknown age, 100 feet; D', supposed continuation of D beneath the hill.

As this belt is but little traversed by roads which have been at all graded, and as its surface is covered by a dense tangle of scrubby vegetation, it is not easy to obtain sections which reveal the nature of the underlay. At Woods Hole and thence northward for about 4 miles there is abundant evidence that the moraine rests upon a ridge of older deposits. On the western face, nearly as far north as Gunning Point, the underlying clays of the older series can be traced, rising from the shore to the height of from 60 to 80 feet. Here and there along the main highway which skirts the shore to Monument River the conditions of the soil and the level of the streams also indicate that the same ridge of older rocks persists beneath the morainal cap, attaining perhaps at some points between the valleys of the brooks a height of more than 100 feet above the level of the tide. On the east side of the ridge the streams and lakes show by their levels that the ridge continues on that side of the moraine. The facts justify the conclusion that the greater part of this morainal ridge rests on the summit of a pre-Glacial divide which separated the waters of the old Buzzards Bay river from that which formed the valley that is now Vineyard Sound.

With a change of direction from north-south to northeast-southwest the Falmouth moraine is continued southward in the Elizabeth

Islands. In these isles the erratic material is in all cases but a thin overlay resting upon the crest of an ancient ridge cut in the Naushon sands, which are considered the equivalent of the Truro series. At no point, so far as I have observed, does the moraine appear to be more than 25 feet thick. In all the observed localities it evidently rests on the top of a divide formed before the advent of the ice, and it is lacking over large areas, where the stratified sands appear with only occasional bowlders resting upon the surface. Of the mass of material composing the Elizabeth Islands above the plane of the sea, certainly not a tenth, and perhaps not a twentieth, part is of morainal nature. The rest may be of glacial origin, but if so, it was deposited far in advance of the ice and long before the advent of the glacier in this part of the field.

On Marthas Vineyard the main or northern moraine appears at first sight—and even after some inspection—to be made up of bowldery material, but on careful investigation I have found that it is a pre-Glacial ridge, the pedestal being formed of a stream divide cut in the Cretaceous and Tertiary strata. On account of the misleading appearance of the ground, I was led, in my report on this island,[1] much to overestimate the depth of this glacial wall. It has not half the mass stated in that report. It is doubtful if the average depth of the deposit exceeds 40 feet. The ridge occupied by the moraine is not completely covered with the deposit. For considerable distances the top of the elevation is essentially without materials which, from their character or distribution, may be classed as truly morainal. At other points, especially in the middle portion of the belt, on the estate known as "Seven Gates," the deposit constitutes a very characteristic morainal belt, with numerous large kettle holes and with bowlders in such abundance that the masses appear like ruined cyclopean masonry. The southernmost moraine of the island also occupies the summit of a divide, but the erratic element is small in amount and only here and there assumes a morainal character.

In the territory between the two moraines of Marthas Vineyard there are, as before noted, many fields which are so far free from glacial waste that they may fairly be termed driftless. It is not easy to find any material on them that may be classed even as till. Rarely is there a foot, in depth, of this deposit. This driftless character of surface is so complete that the plowshare will turn up Tertiary or Cretaceous beds containing no trace of erratics. Fields of this driftless soil some acres in extent lie within 2,000 feet of the wall-front moraines. On the north side of the principal moraine the same phenomenon of nearly driftless fields is observable, but in a less distinct manner. The areas without erratics are small, and those which are quite without till are at no point, so far as I have observed, more than an acre or two in extent. They occur at the foot of the slope on which the moraine lies, usually

[1] Seventh Ann. Rept. U. S. Geol. Survey, 1886, p. 312.

quite near the sea level. This feature of small driftless areas over which the morainal matter must have passed on its way to the glacial front indicates that the conditions which determined the deposition of the detritus were peculiar.

There is another peculiarity of the Marthas Vineyard moraines which appears to throw some light on the conditions of their formation. While commonly the ridge of detrital material is placed on the very crest of a divide, adding distinctly to its height, it not infrequently is deposited as a sheet on the southerly or outer face (outer in relation to the glacial movement) of the ridge on which it was formed. The effect is as if the materials had been pushed up the northern slope and had fallen into the attitude in which they are found.

In the case of the Cape Cod moraine the evidence is sufficient to show that the mass occupies the considerably elevated surface of a ridge which was formed before the advent of the ice. This ridge continues with no complete interruption from the base of the cape to Orleans, except for the rather deep and wide break at Bass River. So far as I have been able to determine, the moraine is gathered mainly on the southern side of this ancient divide, though it generally rises somewhat above the crest line. The feature noted on Marthas Vineyard, of considerable areas of the more ancient deposits without glacial waste, is noticeable to the north of this moraine, but is less extensively developed than on that island.

On Nantucket the moraine appears to crown the summit of an elevation composed of the Sankaty beds, which probably belong to a time immediately preceding the deposition of the Nashaquitsa series. The conditions are not clearly indicated, but there is little reason to doubt that this relatively unimportant accumulation is placed as are the others above noted.

The facts above described warrant the statement that all the characteristic morainal accumulations of this district are placed in singularly close relations to the crests of ridges which existed before the ice sheet invaded this district. The few apparent exceptions prove on examination really to be not such. Of these the most striking is the case of the northern moraine of Marthas Vineyard, where the bowldery deposit descends into a valley about the headwaters of Witch Brook. In this relatively low place, which still is about 70 feet above the sea, the moraine becomes somewhat scattered. It is, in effect, a rather flat, very stony field, in place of the well-defined accumulation exhibited on the higher ground on either side. So, too, the same morainal, detached hills which lie here and there on the north slope of Cape Cod and Marthas Vineyard appear on inspection to be small elevations of the Barnstable series, which bear some coarse drift or else masses dropped from a stranded iceberg.

The relations of the moraines in this district can not be explained on the supposition that these deposits are revealed only on the highlands,

being elsewhere covered by later accumulations of washed sands. This suggestion would not be entertained for a moment by any student of the district who approached the problem without a decided preconception; although, as I know from experience in making the examination, it requires rather careful observation to avoid the mistake of supposing that the whole mass of these several ridges is of a morainal nature.

So far as I am aware, none of the moraines of the central and western portions of the country are placed on the crests of divides in the manner shown to be the rule in this shore-land district; nor am I aware that any of the accumulations in the interior parts of New England occupy the crests of ridges, except when their bases may accidentally coincide with those elevations. It therefore may be fairly assumed that there has been some peculiarity in the condition of the glacier in this part of the country which has served to bring about the curious result. I have not been able to determine the precise cause of this occupation of the preexisting divides by glaciers, but the possible explanations appear to be but two, and these will be briefly stated.

The first hypothesis is that the ridges may have served in forming a moraine by arresting the flow of the ice, already languid in its movement, for the reason that it had become attenuated at its margin. Hanging on these crests its front may have been retained in one position for a considerable time, which permitted the accumulation of the morainal deposit. The difficulty with this view is that it does not explain the absence of drift in the fields near the well-developed morainal lines. The second hypothesis is that, the region being depressed beneath the sea to a considerable but unknown depth, the ice, while remaining as a united sheet, may have floated over the valleys, grounding only upon the ridges and there depositing its contents of rock material. The portion of the ice which was shoved over the crest was probably broken into fragments which floated away. This hypothesis will explain the absence of till on much of the lowlands where, had the ice rested on the surface while it melted, it should remain to mark the decay of the sheet.

The hypothesis of the partial floating of the attenuated ice sheet finds a certain amount of support in the evidence which goes to show a considerable subsidence during the period of formation of the sand plain in front of the moraines. As I have elsewhere shown, these plains were certainly formed under water while the land lay at least 100 feet lower than its present level, and the actual depth of the submergence may have been much greater than the minimum required for the construction of the plains. The hypothesis will perhaps serve to explain also the departure of the Cape Cod moraine from the normal direction. As before remarked, it is very difficult to see how a glacier moving under ordinary conditions would have a path parallel to the shore; but if the sheet be conceived as floating in the sea, though its

course might be generally eastward, its margin might be pressed continuously or from time to time against the submerged ridge on the south, on which would be dropped, as the ice sheet shattered or broke up into bergs, a portion of the contained débris. The main objection to this hypothesis is that evidence as to the actual floating of the ice over the valleys is lacking; yet it demands only conditions which must exist wherever a glacial sheet enters the sea, pushing out into water so deep that the mass leaves the lower-lying parts of the bottom. Somewhat in its favor is the fact that over the nearly driftless fields near the Marthas Vineyard moraine occasional large solitary erratics are found, and sometimes heaps of coarse débris in positions which suggest that the materials have fallen from the base of a floating glacier or from an iceberg.

It must be confessed that both hypotheses present serious difficulties; but in view of all the facts, the one last stated is more satisfactory than that of marginal lobes producing interlocking moraines—a hypothesis which does not seem applicable to this field.

RELATIVE AGE OF THE MORAINES.

The relative age of the moraines in this district affords an interesting field for inquiry. The only criterion which appears to be accessible is that which may be derived from the comparative amount of decay of rocks of apparently the same measure of resistance to such change. Judged by this test, the moraine of Cape Cod is to be regarded as rather newer than that on Marthas Vineyard; the bowlders of like petrographical species are less broken up, and interstitial decay has penetrated to a much less depth. These determinations are based on mere inspection, but the impression thus obtained by many successive visits to each field at short intervals is clear.

Much evidence as to the petrographical nature of the hidden rocks of southeastern Massachusetts and the neighboring sea bottom can doubtless be obtained from a careful study of the materials in these moraines. This task has not been formally undertaken in the preparation of this report, but incidentally certain points have been noted, of which only one need be mentioned here, viz: On Marthas Vineyard the drift abounds, in a remarkable manner, in masses of chalcedony, some of which are a foot or more in diameter. The pebbles are so numerous that many tons could be gathered on a mile of beach on the north shore of the island. This material is not found on the mainland, nor is it known on the moraine of Cape Cod. It is therefore probable that it was riven from the area now covered by the sea.

CLAY BOWLDERS IN TILL.

The till of Cape Cod, especially where it occurs in the moraines, or has a morainal aspect, occasionally contains large masses of clay which evidently were brought to their resting places in the manner of other

erratics. These masses can be found scantily at several places on the cape. They were most clearly shown in an artificial escarpment which for some years existed near the steamboat wharf at Woods Hole, the site of which is now occupied by the Nobska House. In the excavation of a low drumloid hill which existed at the place just mentioned, a dozen or more of these clay bowlders, varying in diameter from a few inches to 6 feet, were noted by me in the course of three or four visits to the locality. Traces of the same bowlders have been seen on the northern slope of the cape and in the district about "Quisset" Harbor. As such bowlders have not been found on Marthas Vineyard in the numerous sections of similar drift materials, it is desirable to seek an explanation of the peculiar limitation of their occurrence. These conditions seem to have been as follows:

The clay of which these bowlders was formed was of a tenacious, uniform quality. Although much oxidized, it was seen to be of the same general character as that found in the brick-clay pits of the region about North Barnstable. That the clay was rather soft when it was moved is indicated by the fact that the surfaces of the masses were crowded with pebbles, in the manner in which lumps of clay, made by the waves on the seashore from the waste of clay cliffs, are coated with a layer of pebbles which have been pressed into the mass. As the glacier evidently slipped over the surface of such clays wherever that surface was of a continuously sloping form, as it now is on the northern versant of the cape, it seems likely that these bowlders were riven from areas where the ground was cut into deep ravines after the manner of the so-called bad-land topography—conditions which would favor the formation of erratics. That such irregularities existed in the cape area is sufficiently shown by the irregular "noses" or projections of clay—the so-called clay "pounds" which have been dug into here and there to obtain materials for bettering the sand roads of the district. So far as I am aware, clay bowlders as large as those at Woods Hole have not been found in other regions. Their rare occurrence is perhaps attributable in part to the fact that a deeply indented topography, formed in soft clays, has rarely been so eroded by an ice sheet. (See Pl. XCIX.)

LENTICULAR HILLS.

The class of drift deposits known as lenticular hills or drumlins is practically wanting in the southeastern portion of Massachusetts. There are no instances in which elongated arches of till are sufficiently well developed to merit a place in this group. Here and there, however, are morainal hills which show distinct traces of the action which gives rise to these regular forms. The ridges north of Woods Hole, between that village and Quamquisset Harbor, closely approach in shape what would be termed drumlins of the lowest order if they lay in the central part of Massachusetts. So, too, on the north side of the

cape, some of the drift hills in the town of Bourne show traces of a like regularity of outline. On Marthas Vineyard several of the morainal ridges in West Tisbury and Chilmark, especially that known as Prospect Hill, are distinctly of a drumloid form.

The arched hills of the cape district are, so far as I have observed, limited to the higher ground, and they approach more closely a symmetrical form as the altitude above sea level increases. This is not the case in the more northern parts of the coast of Massachusetts, for about Boston Harbor and in Ipswich very perfect specimens of the type are formed rising from the sea level. In any discussion as to the origin of these curious topographical forms this peculiarity of their distribution must be considered.

It is noteworthy that in this district the drift hills are more shapely on the side against which the ice moved than on that which was turned away from the stream, and also that the ridges of the pre-Glacial topography cut in the sands, gravels, and clays of the Cretaceous, Miocene, and Pleistocene formations have been in many cases rounded into drumloid forms. This is particularly the case on the western side of Marthas Vineyard, though instances of the same nature exist on the central and western parts of Cape Cod. Some of the hills near the Chatham Harbor margin of the Truro beds have a distinctly drumloid outline. (See Pl. XCIX.) These facts clearly point to the conclusion that whatever may have been the cause which led to the local deposition of the deep sections of till composing characteristic drumlins, the final shaping of these forms was due to the action of the ice as it passed over them.

WASHED DRIFT.

In this field, as elsewhere in New England, the washed drift may be divided into three tolerably distinguishable groups: eskers (nearly absent here), pitted plains or kames (rare), and sand plains or morainal aprons. It is to be noted that the materials composing these deposits differ less from those of the ordinary till than is usual in the more northern parts of Massachusetts. Here the till itself is always very sandy, its pebbles are much rounded, and the clay element, as compared with the more northern localities, is relatively small in quantity. This feature is probably due to the diminished cutting power of the glacier on its outer margin and to the extent to which its detritus was worked over by the water which flowed beneath the ice on its way to the front of the sheet. The result of these actions was to diminish the total amount of the till and to make the remaining portion much sandier here than elsewhere. As a consequence of this, it is often difficult to distinguish between the drift which has been deposited in water and that which has been left upon the surface by the melting of the ice in which it was contained.

One of the eminent peculiarities of this district is the general absence

of eskers. So far I have not been able to find any characteristic examples of these structures on Cape Cod. In the region from Bass River to Orleans there are certain ridges extending in a north-south direction which may possibly belong to this group of deposits, but I suspect that they are the remains of the ancient topography cut in sands of the Truro series. I am the more inclined to this view for the reason that the one ridge on Marthas Vineyard which I identified in my report on that island as an esker has since been proved by a section to be an old pre-Glacial feature, slightly modified by a coating of washed drift or very sandy till.

The probable absence in this field of eskers of the molds of the caverns in which flowed the subglacial streams goes to support the hypothesis that the ice in this section did not generally rest upon the surface, but came in contact with it only on the higher parts of the ground. Thus floating, there would be no chance for the development of the ice-roofed channels, the shapes of which became elsewhere molded in the débris with which they were in time filled. As these eskers descend to the level of the sea in the district about Boston, and are found in the region north of a line stretching from Boston to Narragansett Bay, it may, perhaps, be inferred that the conditions which are indicated in the Cape Cod district were of a rather local nature.

Pitted plains of the type so common in the districts where eskers exist are not often found on Cape Cod or in the islands to the south. The only good examples are on the frontal apron south of the moraine, where ice remnants, icebergs, or ground ice left by the retreating glacier appear to have been partly buried in rapidly accumulating sands, leaving where they melted depressions to indicate the positions they occupied. A trace of the same action is found in the central part of the great plains of Marthas Vineyard, where the occurrence of a small lake with steep sides can be accounted for only on the supposition that its site marks the place where a stranded iceberg was buried in the accumulation of sands which constitute the mass of the morainal apron.

An ordinary type of kame deposits, consisting of a number of hillocks of arched form huddled together quite without definite arrangement, a type very common in the town of Plymouth, appears to be lacking in the cape and islands. This peculiar local topography of the washed drift can most readily be explained by supposing that when the ice came to the point where it ceased to rest in the bed rock and began to float, its under surface would for a time retain the form impressed upon it by the contours of the surface over which it had flowed. There would thus come to be a space between the base of the rotting ice and the sea bottom into which the débris coming from the land would naturally be crowded. If the ice had much movement the resulting shapes of the drift would of course be destroyed, but at a late stage in the retreat of the glacier its stagnation might be so far complete as to leave the molded sands and gravels as we find them. The occurrence of this

remarkable kame topography on the mainland and its absence on the neighboring peninsula and islands is what we should expect on the hypothesis that the ice was in part afloat in this portion of the field it occupied.

The characteristic form of washed drift occurring on Cape Cod and the neighboring islands is the deposit of sand and gravel laid down in front of the moraines. These deposits are more extensive in this district than in any other known to me except, perhaps, on Long Island, New York. It is to be noted that these great morainal aprons differ in certain ways from the sand plains of the mainland. On that field the plains are in most cases at the end of distinct eskers, and clearly mark the places where a subglacial stream passed into the open air or open water. They are rarely, if ever, distinctly related to the axis of defined morainal ridges, though we often find bowldery tracts at about the point where the esker passes into the plain. In these morainal aprons of the cape district, on the contrary, there are no eskers leading to them, but the broad field of sand extends up to or near the wall of coarse débris. Next this wall there is commonly a shallow, wide depression, from which the apron rises to a point somewhere about a mile away, whence it declines to the sea. Such is the form of the great plains of Marthas Vineyard and Nantucket. In Cape Cod the depression or ditch is less distinct; it will, however, be remarked by an observer who has noted the feature elsewhere.

While the ordinary sand plains have their "feeding" eskers—molds of the channels through which the débris came—those that front the great moraines of the cape lack these features. Here and there are breaches or low places in the morainal walls through which currents of water appear to have flowed, as is shown by the signs of erosion in the channels in front of these breaches. The plain exhibits broad, irregular channels which lead down to the sea. These scour ways do not appear to have been at any time occupied by open-air streams, but rather to have been excavated on a water-covered surface. This feature, like the ditch in front of the moraine, is less distinct in Cape Cod than on the neighboring islands, yet it is disclosed to close inspection and partly indicated on the topographical map. In reports on the geology of Marthas Vineyard[1] and on the geology of Nantucket[2] I have given in some detail an account of the characteristics of the plains that lie in front of the moraines on those islands. The like deposit on Cape Cod differs from those noted in the papers referred to in that it is ruder in form, that it has numerous considerable lakes on its surface, and that the scour ways are generally occupied by brooks.

The peculiarities of the morainal apron on Cape Cod, taken along with the evidence of beds of clay apparently belonging to the Barnstable series, lead to the conclusion that in place of the very deep deposit

[1] Seventh Ann. Rept., U. S. Geol. Survey, 1885–86, p. 316.
[2] Bull. U. S. Geol. Survey No. 53, 1889, p. 19.

of sand which exists beneath the plain on the above-named islands we have a relatively thin layer of detritus imposed upon a preexisting topography which is cut in rather impervious beds. The numerous swamps and lakes, as before remarked, so high above the sea that their waters could not be retained by sand barriers, are probably to be in part accounted for by the supposition that they lie in valleys which originally drained northward, as appears to have been the case with nearly or quite all of the pre-Glacial streams of the cape. These streams were dammed by the moraine. In perhaps larger measure, however, these basins are to be regarded as the molds of ice remnants about which the washed sands were gathered. That such was the case is shown by the fact that the sides of the depressions are usually very steep, the detritus having slopes which it could not have assumed at the time of its deposition unless there had been some barrier, such as the walls of ice would have supplied, to keep it from being conveyed into the cavity.

The contours of the great plains of Cape Cod, like those on the islands, clearly indicate that the material was deposited under water. In aerial overwash plains, formed as detrital cones, we find necessarily a continuous down-sloping surface. In these plains in front of the glacier of southeastern Massachusetts the surface has the gently rolling character characteristic of sands that have been arranged on the bottom of a sea which was the seat of tolerably strong currents. The slope of the Cape Cod morainal apron is essentially the same as that of the similar structures in this district, the rate of the decline to the seaward being from 12 to 15 feet to the mile.

The surface of the plain of Cape Cod is prevailingly composed of rather fine, siliceous sand. This material forms a bed having a rather remarkably even thickness of from a foot to 18 inches. This usually passes downward by a rather sharp transition into a pebbly layer in which the pebbles are from the smallest sizes up to that of a cricket ball, though rarely so large. At greater depths the admixture of sand and pebbles is rather uniform, the mass having obscure stratification. Now and then a bowlder is found. These bowlders are almost always rounded and rarely exceed 2 feet in diameter; they are often found in groups associated with gravel, and they occasionally occur on the surface. Such stratification as is exhibited is not distinctly cross bedded. In these, as in most other features, except the presence of numerous lakes, the cape plain in no way differs from the like structures in the other parts of the district.

In considering the origin of these morainal aprons of southeastern New England, the fact should be noted that deposits of like nature do not, so far as I am aware, exist in front of the moraines in the interior of the country. There are there, it is true, traces of overwash plains, but they are always much less continuous; they have, in a word, more of the nature of detrital cones. Those I have seen in Ohio, Michigan,

and Wisconsin also lack the depression next the moraine, the pits occupied by lakes such as occur on Cape Cod, and the scattered bowlders in the mass and on the surface of the deposit. The difference between the structure in the two districts probably arises from the fact that those in southeastern Massachusetts were formed under water, while those in the west were deposited mainly in the air. If we suppose that the sea extended up to the ice front, and that the finer materials were, at the time of melting, given into the control of tidal currents, we can well conceive that the part of the débris which could be thus transported would receive a wide distribution over the neighboring bottom; the floating ice would convey many bowlders from the front of the moraine, dropping them haphazard as they melted; the tidal currents would carve channels on the bottom as they cut them on any sands over which they may flow. In a word, the assemblage of conditions exhibited in the morainal aprons is more consistent with the supposition that they were formed on the sea floor than in any other manner.

It will be noted that a number of the peculiar features of these moraines together tend to show that this district was rather deeply submerged at the time of their formation. I have, as yet, been able to find no evidence going to show whether the submergence was so deep as to cover the tops of the morainal walls. It may be noted, however, that on Marthas Vineyard the portion of the moraine which faces on Tisbury River has no apron on its front, but rather a steep overwash plain or long detrital cone which terminates in a valley that may have carried the wash from the glacier down to the neighboring great apron. It thus seems probable that this portion of the morainal front lay above the level at which the sea was placed at the time it was formed.

OUTER LIMITS OF THE CAPE COD ICE SHEETS.

In view of the fact that the ice sheet on this portion of the Atlantic coast was evidently thin, the question arises as to its probable extension beyond the limits to which it can be traced by the remains it has left upon the land. On Cape Cod we find in the Truro-Wellfleet district very slight evidence—if it be, indeed, evidence at all—that the ice lay upon the surface. I am quite prepared to believe that the drift in this area is due to the action of floating ice dropping the waste it carried upon the bottom. We may from the evidence fairly conclude that we are here near the eastward margin of the effective ice sheet.

On the south the extension of the glacier appears to have been to a relatively farther point than in the east. On Nantucket there is a small area of low but fairly characteristic moraine with a well-developed frontal apron. On the island of No Mans Land, south of Gay Head, we have an extensive deposit of a till-like nature, which may, however, be due to floating ice. On the southernmost of the Elizabeth Islands the glacial drift, though scanty in amount, is still sufficient to attest the presence of the ice in that part of the field. It thus appears that

the glacier probably extended its action over all the district of Cape Cod, though on the extreme south and east the effects which it exercised may have been due to portions of the ice which had been broken from the united mass and which were floating in the open sea. It is hardly to be supposed that a sheet so thin as the glacier was in this part of its course could have held together for any considerable distance from the shallows, capes, and islands where we last trace it.

In closing this portion of the report attention may be called to the value of the information concerning the frontal condition of the glacier which southeastern Massachusetts affords. In no other section of the country are the data for inquiry so ample—and, it must be confessed, so difficult to interpret.

POST-GLACIAL DEPOSITS.

This group of deposits includes the spits, hooks, and beaches, the dunes, the marine marshes, the fresh-water swamps, the soil, and, finally, the sea shoals.

One of the first-named group of constructions we have in the hook which constitutes the whole of the area of the town of Provincetown, one of the finest existing examples of such forms. There is certainly none other of its kind in this country which so well deserves attention. The history of this feature appears to have been in general as follows:

When, after the disturbances of level which attended the last Glacial epoch, the land of Cape Cod came to its present apparently stable attitude, the elevated country of Truro extended somewhat farther to the north and east than it does at present. As this last portion of the cape in the east was worn down by waves and currents in the manner in which the work is now going on, the débris was, in part at least, carried to the end of the land, there beginning the growth to the northward of the spit. As noted by Prof. W. M. Davis, the sea beach at the north end of the Truro highland marks the point where the encroachment of the sea was arrested by the beginning of the accumulation of sands which has extended to the village of Provincetown. (See Pl. CII.)

It seems likely that there was shoal water where this spit was formed; before it began to form, indeed, the erosion of the northern face of Truro, which has just been noted, may have been part of a considerable wearing that had gone on before the spit had begun to form. There is a bit of evidence on this point drawn from the results of the "driven" wells sunk in the sand at Provincetown which, though not certain, has some value on this point. These wells, which were sunk to a depth of a few feet below the level of the sea, in place of yielding the very pure water which elsewhere has been obtained from such spits, have afforded a quality which, on account of the large amount of iron it contains, is hardly fit for use. Water of the same

nature is characteristic of the old sands of pre-Glacial age wherever they have been tapped in this part of Massachusetts, the defect being due to the complete oxidation of the considerable amounts of iron which they contain, and perhaps to other chemical changes, such as do not occur in the clear siliceous sand of which the spits and beaches of this region are made. It therefore seems probable that the water of the Provincetown wells is drawn, not from the beach sands, but from the lower-lying pre-Glacial deposits.

The process of growth of the Provincetown hook appears to have been mainly by successive beaches, each formed in front of the next preceding, and each projecting northward somewhat beyond its predecessor. The supply of sand seems to have come, in part at least, from the wearing of the coast line of the Truro-Wellfleet district, and in part from the sea bottom to the eastward. There has evidently been a balance of actions which of late has served to urge the sand to the northward toward the present end of the cape. It is evident that for a time no distinct hook existed in the end of this spit; its form was somewhat like that of Monomoy, but, probably for the reason that the water deepened beyond the shallow on which it at first grew, the end near its present stage of growth turned westward to form the hook with which it now terminates.

At first the Provincetown spit was evidently narrower than it is at present, but with the carriage of sands northward along the shore the water on the side of the open sea was shallowed by the formation of a broad shelf which enabled a succession of beaches to form, each somewhat farther out than its predecessor, and in this manner the spit has been considerably widened. This process of growth appears not to be continuous. From time to time, with the varying direction and energy of the waves and of the currents which they induce, the beach works in, again to be built out with the resumption of the carriage of waste from the shore southward.

Along with the carriage of sand by the sea there has gone a considerable movement of materials by the wind. This has taken place mainly in a westerly direction from the outside beaches. When the tide is out and the air dry, even a moderate wind will move the finer parts of the material almost as easily as though it were snow, and in great storms quartz pebbles up to the size of peas may be observed to fly along at the height of some feet above the earth. As the wind loses a part of its speed in passing over the surface of the ground, the particles of sand and gravel which it bears soon fall into the eddies of the current, there forming the beginnings of dunes. As soon as these dunes form they begin to march before the wind; the bits slip up the exposed side and pass over the crest into the sheltered sea, where they remain at rest until the whole mass has been shifted forward in the same manner. In this way, by the process of constantly moving the windward layer to the leeward side, the dune slowly marches inland.

Various influences tend temporarily to arrest the march of these Provincetown dunes, as they do all such masses of wind-blown sand. As the bits journey they decay, so that they naturally cement together. Moreover, certain species of plants, such as the beach grasses, have developed the capacity to grow in the arid soil of these ridges. This they do so effectively that their roots and leaves make a mat which deprives the wind of access to the heaps.

In the present state of the Provincetown spit hook the structure appears, as a whole, to be in a tolerably balanced state, a condition into which such structures are apt to come at a certain stage of their growth. The cape does not appear to be extending northward, unless it be very slowly, the tidal currents from the bay interfering with this growth. The hooked extremity, which is made up of detritus that washed around the end of the cape, does not appear to have gained in extent in a material way during this century. The only change which menaces the established order of this unstable new land is the present inward movement of the beach on the eastern side, near Moon Pond. There we have a well-recognized danger that the sea may break through, with the result that the valuable harbor of Provincetown would be endangered. It certainly would become shallower, and it might be so far changed as to lose its present great importance as a port of refuge.

The erosion of the sea on the eastern face of the cape from the northern end of Truro to the central part of Eastham has provided not only the sand which has gone to construct the Provincetown area, but also that which, moving to the southward, has built the large and beautiful line of barrier sand beaches that extends from opposite Chatham Center to the end of Monomoy Island. Although this isle is at present separated from the mainland of the cape by a shallow water way, it is, in its structure, a spit of the same general character as that at Provincetown, only less far developed. Already at its southern end it has begun to form the hook, which is the appropriate finish of such spits.

The amounts of débris which have gone both ways from the erosion district of the eastern face of Cape Cod appear to be nearly equal. The reason why the Provincetown spit is so much longer than that of Monomoy is, that the greater part of the sand which moved southward has been used in constructing the extensive barrier beaches that lie on the sea side of Orleans and Chatham; for these long and broad walls of sand probably contain rather more material than is held in the much more conspicuous spit hook at Provincetown. At present the Monomoy spit appears to be growing more rapidly than its northern equivalent, so that in time these two geographical growths may become even more alike than they are at present.

On the northern shore of Cape Cod, although there are no parts of the shore which are undergoing erosion, there is an interesting system of barrier beaches, which has been constructed since the land assumed

its present level in relation to the sea. The material for these beaches has evidently been derived from the shallow bottom of the adjacent bay, it being dragged in to the shore by the action of the waves. It will be observed that while on the eastern and southern sides of the cape these beaches are always drawn near the shore, so that the lagoon they shut in is quite narrow, those on the western and northern shores depart widely from the coast, so that they inclose broad fields of water, such as Wellfleet Bay now presents or such as were found at Barnstable before the harbor was narrowed by the extensive growth of marine marshes. The reason for this more remote position of the barrier beaches in relation to the shores is, that the water on the north side of the cape appears to have been, in the beginning of the present conditions, as it is at present, shallower and with a more gently declining bottom than it had on the south. In fact, the old river basin, which is now Cape Cod Bay, had evidently a much more gradual slope than had the neighboring basins on the south. Thus the ancient form of the basin has served to qualify the shapes of the existing shores.

On the southern side of the cape the evidence of coastal erosion is somewhat the same as it is on the eastern part of the area. In certain places along this shore there are evidences of considerable but variable localized coastal erosion, the waste from which is distributed along the shore and accumulated in slight barrier beaches and hooks. Of these the most interesting is that known as Point Gammon, at the mouth of Lewis Bay. At certain places, as, for instance, at Chatham lights, observations show that for a number of years the recession of the shore went on in a singularly rapid manner, at the rate, it is said, of 10 feet per annum. It is evident, however, that this was a local adjustment of the shore, caused, it is now asserted, by the development of the beach which extends to Point Gammon, and the consequent change in the distribution of the wave action. The amount of erosion on this southern shore has probably been but a fraction of that which has gone from the eastern face of the cape, where, in Truro and Wellfleet, an extensive salient, probably amounting in area to not less than 30 square miles, has been cut away to afford the débris which has been distributed on the beaches, spits, and hooks on the north and south. That the erosion on the eastern face of the cape diminishes in a westerly direction is shown by the unembarrassed outlets of the streams which enter the sound along this shore. If there had been any considerable amount of erosion here, the sands therefrom would have been gathered in adherent and barrier beaches and spits, such as exist along this coast wherever the sea has been supplied with materials from which to make these constructions.

On that portion of the western face of Cape Cod which is bordered by Buzzards Bay we find but little evidence of marine erosion. There are a few very small spits, but no barrier beaches; in fact, there are few portions of the coast south of Boston which are exposed to waves of

moderate severity where the amount of work done by the sea is so small as it is here.

This glance at the shore conditions of Cape Cod shows us that only a small part of its periphery indicates any considerable amount of wasting since the land came to its present altitude. The maximum recession can not well amount to more than 3 to 4 miles. This occurred on the eastern side of the Truro-Wellfleet coast. The next most considerable loss is on the section near Hyannis. The best evidence as to the limited amount of the loss of area is afforded by the fact that the extent of the cliff shores of the area is limited; even the frail materials of the morainal aprons have not been much cut away, as is shown by the fact that their slopes are, with rare exception, prolonged down to the level of the tide. Had they been much eroded they would face the shore in steep cliffs.

Owing to a considerable local erosion which has taken place on parts of the shore of Cape Cod, there has come to be a general opinion that the peninsula is in process of rapid destruction. This view appears to be held by many well-informed residents of the peninsula. So far is this view from being true that the converse may be taken as nearer the facts. It is altogether likely that the total area of this cape country, including all the marshes, barriers, beaches, spits, and hooks that are attached thereto, is no greater than it was at the time when, by a final step of subsidence, it established its present relations of land and sea. The aggregate of this erosion is evidently much less than that which has taken place on the islands to the south.

The submarine constructions which have been made by the tidal currents in the waters about the cape are probably, in mass, much greater than are those which appear above the plane of low water. An inspection of the Coast Survey maps discloses in the soundings a curious tangle of shoals, mostly ridge like in form. As before remarked, some of these submarine elevations are probably the divides of the smaller streams which intersected the floors of the valleys at the time they were above the sea. This is clearly the case with Stone Horse Shoal, and it is most likely so with the middle ground of Vineyard Sound. Others, especially the group about the eastern entrance to Nantucket Sound and that at the north end of Muskeget Channel, are evidently due to the action of the strong and contending tidal currents which sweep through these areas of sea. It may be noted here that the absence of any signs of marine current action on the surface of the land of Cape Cod or the neighboring islands and mainland above the level of the sand plains is tolerably good evidence to show either that the Glacial submergence did not extend above that level or that, if more deeply submerged, the ice remained on the surface until the land was reelevated to about its present height.

MARSH AND SWAMP DEPOSITS.

The marine marshes of this district are of considerable extent within the limits of the cape; their area is about 11,000 acres, the greater portion lying on the north side of the isthmus, in the Barnstable and Wellfleet reentrants. On the south and west coasts they are distributed in numerous small areas along the banks of the smaller drowned valleys and in the lagoons lying between the barrier sand reefs and the shore. As compared with the similar marshes north of Boston Harbor, these of Cape Cod exhibit a much less energy of growth. Basins which there would have been occupied by completely developed deposits are here but imperfectly covered by them. The reason for this deficiency is not to be found in any change of species, for these are the same in both districts, but probably in the fact that the amount of mud swept in by the tide is here very small as compared with what it is elsewhere; the result is that the plants are ill fed and do not attain anything like the vigor of growth which they exhibit when the water at each flooding brings much nutritious material to the plant roots. Moreover, in these sandy bays the eelgrass, which is the most effective agent in preparing the shallow water to be occupied by the marsh-making growth, does not do so well on the bottoms of drifting sand as it does on those of firmer and more supporting nature, such as are found to the north.

The fresh-water swamps of Cape Cod were originally very numerous. Though by far the greater number of them have been drained for use as cranberry plantations or converted into reservoirs to flood the vines in the proper season, some areas still remain in their natural state. In its original condition this district had a larger share of swamp grounds than any other equal area in this part of New England, and the inundated fields were more evenly distributed than elsewhere.

The reason for the great development of swamps on Cape Cod is to be found in the fact that there is a clay underlay beneath the glacial sands on the greater part of the area. Thus, the plain of the morainal apron, which in the equivalent deposits of Marthas Vineyard and Nantucket, because it is of pure sand to a great depth, is almost destitute of swamp deposits (that of the first-named island being quite without swamps), is on Cape Cod beset with lakes and with swamps which have grown in lake basins; moreover, the ridge of the old divide on which the moraine rests is wide and rather flat, which favors the development of many areas of imperfect drainage. These conditions have served to give to this region its long-continued predominance in the industry of cranberry planting. There is probably no other place where the very peculiar conditions required for this singular form of agriculture have been so well assembled.

The fresh-water swamps of this region are much better developed than are the marine marshes. The climate and soil are so dry that there is

no trace of the climbing action of the bog sponge which is so common in Maine and is still notable about Boston. This general dryness somewhat arrests the growth of the peat deposits, but it favors that of many species of bushes and some trees, such as the swamp maple and the tupelo. The result is that a large part of the peaty matter of the bogs in this district is due to the leaves and stems of phænogamous plants. On this account the bog soils are evidently more fertile than are those formed by the decay of mosses alone. It is in part to this cause that we must attribute the excellence of the cranberry plantations.

It is a noteworthy fact that a very large proportion of the lakes in the cape district have escaped the action of the swamp-making agents. Many of these basins not exceeding half a mile in diameter show no trace of peaty growth about their borders. This feature is probably due in part to the very sandy character of the shores, which makes it difficult for the mosses to become implanted there—a difficulty which is the greater for the reason that the range in the level of the water is very great. In part the hindrance arises from the considerable depth of many of these ponds and the steepness of their beaches, which makes it hard for the water lilies and rushes to take root, so that the protection which their stems afford the shore from the assault of the waves is lacking. The result is that the frail beginnings of a moss plantation are likely to be broken up long before the growth has attained the strength which would enable it to resist the action of the waves.

SOILS.

The soil of the cape differs little from that of the neighboring districts of the mainland and the islands On the north shore, from the base of the peninsula to Orleans, the general presence of the Barnstable clays or the clayey till made therefrom causes the fields to retain moisture in a way they do not in the more southern and eastern sections. On this account, rather than for any special nutritive value in the underlying material, the soil here is considerably better suited to farming than elsewhere. The vegetable matter on which the fertility of the earth so largely depends does not pass out by decay as speedily as it does in the excessively porous débris which generally underlies the surface in these fields.

Owing to the exceedingly sandy nature of the till, except, as before remarked, where it rests upon the clays of the shore, there is little difference between the soils formed on it and those formed on the sand plains lying south of the moraine; in each condition the portion of the earth which is mingled with decayed organic matter, i. e., the true soil, is rarely more than 6 inches in thickness. As the mineral matter in the drift beds of this region is exceedingly well adapted to afford the mineral elements required by vegetation, the failure of a soil to form is rather curious. The reason for the condition seems to be that the

exceedingly porous nature of the earth affects plants injuriously; in the first place by causing their roots to become very dry shortly after a rain, and in the second place by permitting the speedy and complete decomposition of the decaying organic matter, so that the earth is without the necessary amount of humus. The validity of this hypothesis is shown by the fact that wherever we find a place in which the water table is retained sufficiently near the surface to permit the tilled zone to be moistened by capillary attraction from below, there we find excellent ground for tillage; moreover, wherever the plan of plowing in green crops is followed, the results show that the soil needs only suitable treatment to give excellent returns. A considerable personal experience in tilling such soils as the sandier kinds of Cape Cod enables me to say that where they can be irrigated and where they are provided with nitrogenous matter by the inexpensive plan of plowing in crops of peas, clover, or other leguminous plants, they can be made to yield profitable crops.

It is particularly desirable to have the treatment of these soils of southeastern Massachusetts made the subject of a special and well-directed inquiry. In this district we have an aggregate area which may be safely reckoned at not less than 150,000 acres whereon all efforts at tillage have ceased. The region was once fairly well wooded, but the forests have long since been cut away and their regrowth is prevented by the numerous fires which sweep over them and which still further reduce the amount of vegetable matter in the soil. These fields, when unwooded, are sold, in the rare transfers which are effected, at from 50 cents to about $3 an acre; in their present neglected condition they are really not worth any price. In view of their nearness to rail and water transportation they should invite the attention of persons who are willing to take the pains necessary to learn the most economical methods of bringing them into tillage. Sixty years ago the swamps of this district were even more unpromising fields for agriculture than these sand plains and hills, yet at the present time, in their condition as cranberry bogs, they are worth on the average more than $100 an acre over and above the expense of bringing them under cultivation.

Of the total area of Cape Cod, only about one-eighth is so occupied by morainal matter as to be untillable; about another eighth is contained in the sand spits and beaches; so that three-fourths of the whole area is, so far as the geological conditions go, fit to be made into soil, and will doubtless in time be brought under cultivation. The morainal fields afford excellent ground for the culture of forests; several species of trees do well on this bowldery earth, among which may be mentioned the white pine and the Scotch larch, both of which grow rapidly and are free from diseases. In the occasional swamps, so placed that they can not be used for cranberry culture, the swamp cedar, which affords with a rapid growth valuable timber, may be advantageously grown.

Perhaps the only land quite unfit for profitable use is that of the washed and blown sand of the beaches and spits. In the earlier conditions of our agriculture, lands such as those of Cape Cod were not worth attention. At the present time, with the increasing use of fertilizers and irrigation, these fields are likely soon to be made productive.

The facility with which water can be stored in the elevated lakes of Cape Cod invites the use of irrigation on much of its area. From a rough eye estimate (there are no maps good enough to warrant a closer study) I judge that not far from 10,000 acres of the peninsula could be effectively watered.

HARBORS AND WATER WAYS.

In the conditions of navigation down to within sixty years of the present time the harbors of the cape were well suited to shipping. Owing, however, to the fact that these havens, with the exception of that at Provincetown, owe their basins either to flooded valleys, such as Oyster Bay, or to irregularities in the morainal fields, such as Woods Hole, they are all rather shallow and usually are shut off from the sea by bars and shoals. They are, therefore, fit only for the use of the smaller craft. Several of the ports which once sent forth many commercial ships, as, for instance, Chatham and Barnstable, do so no longer. The only port of value on the peninsula is that of Provincetown, which owes its existence to the formation of the curious beach hook which incloses its basin. The havens fit for use of pleasure boats are numerous; they are, indeed, numbered by the score. No part of the coast south of Maine so abounds in them as does the southern face of the cape. In general, these basins are susceptible of much improvement by the use of jetties, which may confine the considerable tidal water which passes through their excessively wide entrances.

More important in a general sense than the harbors of Cape Cod are the water ways which nearly traverse its width. These may be made passages by which vessels can avoid the dangerous voyage that now has to be made by all craft passing this part of the coast. A sailing vessel bound north or south of the cape has to reckon on an average of about two days' loss of time, as well as a considerable expense in the way of insurance, in making the voyage, at least during the winter half of the year. Except Cape Hatteras, there is no more dangerous portion of the Atlantic coast. The shipping which annually passes through Vineyard Sound on this voyage is said to be greater than that which traverses any like width of water in the world. From an early day there have been projects for cutting through the cape, making use of some one of the several channels—rivers so called—which nearly intersect the peninsula. Of these there are four which, with relatively slight expenditure as compared with other modern ship canals, could be opened to shipping. They are Monument River, Bass River, Town Cove in Orleans, and Pamet River in Truro.

The two last-named ways, though from an engineering point of view most practicable, are situated so far out on the cape that the worst dangers of the voyage northward would be passed before their entrances were reached; they are, therefore, not worth consideration.

The Monument River passage is, from the point of view of engineering, at least as far as opening the way is concerned, a very easy work to construct. It has, however, the peculiar disadvantage that it opens into Buzzards Bay, so that vessels must determine on passing that way from the time they start on their course around the cape. As in good weather the course can be run by a sailing vessel in twelve hours from the anchorage ground near Nobska light, in Vineyard Sound, what mariners need is a way to pass from the waters of that sound directly into Cape Cod Bay. The only passage which will afford this is that by the way of Bass River. This channel is, on the average, deeper and wider than Monument River, and it lies in a position where, at reasonable cost, vessels going northward could be provided with a safe harbor of refuge, whence, if the weather favored, they could turn the cape or could take the shorter artificial way. It is probable that the costs of these ways would not differ in any important measure. The distance from the western ports to Boston via Bass River would be longer by about 50 miles than by way of Monument River; to and from points north of Boston the additional distance would not be worth reckoning.

A considerable disadvantage of the Monument River way is that the upper part of Buzzards Bay, owing to its land-locked and current-less state, often becomes thickly packed with ice, even in winters of ordinary severity. On the other hand, the waters of Vineyard Sound, because they are the seat of strong through-running currents, are rarely thus embarrassed. It may be remarked that there is another improvement in the water ways of the cape which deserves consideration only less than a water way across the peninsula; this is, the passage through the morainal line to Woods Hole. At this point a natural breach of the moraine—one of the many which exist in the moraines of this district—affords a crooked and dangerous passage which has been much in use by vessels since the settlement of the country. A measure of benefit has been done to this way by dredging, but it remains an inadequate passage between two of the largest bays on our shore. If Monument River is to be taken as the site of the canal—and by a nearly common consent it appears to have been thus adopted—it will be more than ever necessary to provide a fit ship channel at Woods Hole, so that vessels may still have some choice as to the open route around the cape after they have entered Buzzards Bay.

Whatever is done in the way of canalizing the cape, it is clearly important that an adequate harbor of refuge should be provided on the south shore, where vessels in times of severe storm may find a safe

anchorage. At present there is no such shelter fit for the use of the larger vessels which ply along the Atlantic coast between New Bedford and Provincetown. The anchorages in Vineyard Sound, with the exception of the small havens at Woods Hole and Edgartown and the breakwater at Hyannis, are all open and exposed to grave danger from the northeastern gales. The most available of these shelters—that at Vineyard Haven—is often very much crowded, so that if the outermost ships should drag their anchors a great catastrophe would be likely to occur, in which scores of vessels might be lost. A considerable number of the shipwrecks which occur where craft are on their way around Cape Cod are due to the fact that there is no perfectly safe place in the waters of Vineyard or Nantucket sounds where they can await conditions of weather which make it fit to essay the passage.

ROAD-BUILDING MATERIALS.

The condition of the highways in Cape Cod is and always has been bad. The sandy nature of the underlay and the prevailing lack of vegetable matter in the soil make this condition inevitable unless some method of hardening the wheel way is adopted. Of these methods there are four which are more or less available at various points: The roads may be covered with oyster shells or the shells of the pecten, known locally as the scallop; they may be covered from time to time with a coating of clay; they may be graveled; and they may be macadamized.

The use of shells is in many ways to be commended where the traffic is light; but when exposed to much travel the covering is swiftly destroyed. Moreover, any general use of this material is impracticable on account of the limited sources of supply. The use of clay as a means of hardening the sands has been essayed in this district, but with poor results. The application on roads of ordinary use has to be made about once in two years, and it is so costly that in the end it is more expensive than it would be to construct a well-hardened way. Of gravel fit for road building, none is known to me except in the extreme western portion of the cape, and this is not of good quality. Thus the only satisfactory resource in this field is found in the use of broken stone, as in the well-known macadamized roads.

As there are no bed rocks attainable in the cape district which can supply material for macadamizing, it is necessary either to import the broken stone from the farther parts of Plymouth or Bristol counties or to make use of the erratics which may be had from the moraine or from the old walls composed of the smaller bowlders which have been gathered from the fields of till. As far out on the peninsula as the central part of Orleans, and within this section southward to the border of the moraine, the amount of this erratic material is great. It is, indeed, sufficient for the needs of road building in this county for all the foreseeable

future. The supply of "field stone," or those which may be had from the surface of the ground, of sizes to be used in the crusher without breaking with the sledge, is limited. It is not likely to serve for more than the needs of original construction of the roads which will have to be built within the next score of years. After that the resort will have to be the pits opened in the moraine, where usually more than half the mass excavated will be large bowlders needing to be blasted in order to be made serviceable.

The petrographical character of the morainal erratics is good. They are mostly of a granite nature, with some admixture of trappean rocks. These dike materials sensibly increase in amount as we go eastward along the moraine. In this direction we find a considerable amount of volcanic débris, mostly fragments of what seem to be indurated ash beds and breccias. As before remarked, the rock masses of this morainal accumulation are not much affected by decay. The experiments made by the Massachusetts Highway Commission in the use of the field stone on the cape—of which about 12 miles of way has already been built, a portion of it having been in use for two years or more—shows that this material is excellently well adapted to building roads. It is so slightly decayed that the amount of small fragments produced is not much greater than is needed in "surfacing" the roads. When this element is excessive an adjustment can be made by sorting the stone before crushing, the product of the softer kind being used in the lower layer of the construction.

Roads made of the bowlders found on the cape can not be expected to have the endurance to traffic that is exhibited by those which have the covering layer composed of the harder traps, such as are found in the region about Boston or in the Connecticut Valley, yet for the uses they have to serve in this district they will prove very good.

The portions of the cape which are ill supplied with road-building stones are those in the southern parts, between the western part of Mashpee and the eastern part of Chatham and the towns of Eastham, Wellfleet, Truro, and Provincetown. In the first of these districts beneath the morainal apron there are, as are shown by various ditches, extensive deposits of pebbles and bowlderets which may afford local sources of supply of stone to be used in the crusher. These should be assayed in order to avoid the great cost of hauling material from the source of supply in the moraine, which is distant and accessible only by very sandy roads. These pebbly deposits seem to lie beneath the beds of the channels which extend from the moraine to the shore. They are usually covered by a thin layer of gravelly sand. The supply for the portion of the cape beyond Orleans will have to be brought by railway from the morainal district, and fortunately the railway extending to Provincetown brings all parts of this section within an average distance of about 1 mile from transportation.

ORIGINAL EASTWARD EXTENSION OF CAPE COD.

The presence of an extensive system of drowned valleys on the Cape Cod district, including therein the islands on the south, leads to the question as to the extent to which these partly submerged lands were originally continued to the eastward. This question can not be fully answered, but some light may be thrown upon it by the facts and considerations which are noted below.

It is at a glance evident that the eastern side of the river valley into which drained the streams on the north side of the cape has been in part cut away. There is nothing to mark its former place except it be in part the shoal in which the Provincetown hook has been formed. This shoal is indistinctly continued northward, as is shown by the soundings, and the general form of the bottom of Cape Cod Bay supports the hypothesis that the valley was continued down to the depth of 100 feet or more below the present level of the sea.

On the floor of Massachusetts Bay and farther to the seaward in Georges Shoal, Cashes Ledge, and other less important elevations we have the elements of what appears to be an ancient land topography. It is possible to explain these features by the supposition that they are due to the warping of the earth or by the hypothesis that they were morainal in their nature, but neither of these views finds any definite support. Warpings of the type required to account for the facts would have to be of a type unknown in this part of the continent, at least in recent geologic periods. Moraines are contraindicated by the slight erosive power the ice evidently possessed and the thin character of the morainal accumulations on the neighboring coast.

It might seem probable that the mountain-building actions which led to the extensive dislocations of the Tertiary strata in this district were competent to bring about the formation of such ridges as we find on the sea floor in this vicinity, but the vast erosion and deposition which has taken place since these disturbances occurred would naturally have led to the destruction of any such reliefs had they been formed. Moreover, there are no indications that the stressing of these beds led to the building of sharp ridges, such as we find in these ledges and shoals. On the contrary, it is eminently probable that the region thus affected lacked at the end of the process any distinct topography except such as was given it by subaerial erosion.

It seems certain that the topography of the sea bottom in and to the east of Massachusetts Bay can not be very ancient. It evidently lies within the limits of the continental shelf—i. e., within the realm of excessive sedimentation, next the shore. Reliefs of such a sharp character would inevitably have been covered by detritus if they had long been in existence. Therefore, the probability seems to be that they are a part of the topography which, in a semisubmerged state, is preserved in the Cape Cod system of drowned valleys.

The cause of the formation of the partly or completely submerged valleys of this part of the shore may perhaps be found in the extensive dislocation which the strata have undergone in this region. If we suppose, as we well may, that the newer deposits of this part of the coast were over a large area much mountain built, the result would have been to lift what was originally a set of level and low-lying beds to a considerable height. A topography developed on such strata would be sharp, and the headwaters of the streams would be at a higher level above the sea than would be the case in the neighboring undisturbed districts. The fact that like disturbances in the region lying to the west and south have been attended by a similar preservation of the ancient topography, as in Long Island and Block Island, makes this view as to the cause of the maintenance of the Cape Cod peninsula the more probable.

In considering the conditions which have led to the formation and preservation of the Tertiary topography in the Cape Cod district, it is well to note the fact that the whole of this portion of the Atlantic coast appears to be at the present time much below the average elevation which it has recently had. This is shown by facts which indicate that the sea has not of late laid at a higher lever than about 100 feet above its present station, while the evidence from the submerged topography leads us to the conclusion that the depression below the level of most extreme elevations has amounted to at least 300 feet, and probably is much in excess of that amount. It should also be said that this submergence is not due to local causes. It is clearly a part of the very general action which has included a large portion of the shores of all the continents. The action is manifested on the eastern coast line of North America, from the mouth of the Rio Grande to the circumpolar section of the continent. It is also to be noted on the Pacific coast within the same parallels.

ABSENCE OF SHOALS IN CAPE COD BAY AND IN BUZZARDS BAY.

The absence of shoals in Cape Cod Bay and in Buzzards Bay apparently indicates a difference in the history of these basins as compared with that of the depressions of Nantucket and Vineyard sounds. The explanation may possibly be found in the fact that the sounds, in part at least, represent a region of adjacent headwaters of several streams the cols of which were in the last great subsidence lowered beneath the sea, permitting the tidal currents freely to pass through them. These streams having a great erosive action on soft rocks, such as underlie this district, are sufficient to account for the effacement of the islands which evidently lay not long ago in these waters. It may also be remarked that the Buzzards Bay River appears to have had a steeper drainage than the other neighboring old streams on the east, which may have accounted for the more complete erosion of the divides

between its branches. It seems, however, more likely that the presence of these shoals in the Nantucket and Vineyard system of sounds is partly to be attributed to the action of tidal currents in this field.

SEAWARD CONTINUATION OF DROWNED VALLEYS.

The soundings given on the coast charts, where the water exceeds about 100 feet in depth, are not in sufficient detail to make it worth while to devote much labor to tracing the probable direction of the ancient drainage channels with a view to ascertaining how near they went to the margin of the continental shelf. We may, however, note certain of the more patent facts.

North of Cape Cod we find a deep channel between Race Point and Stellwagen Bank. The water at the western end of this channel, where it appears to connect with the Cape Cod Bay Valley, has a depth of about 35 fathoms; thence it shoals seaward to about 22 fathoms; still farther to the east it deepens rapidly to about 50 fathoms. The shallowest water in this channel is in the continuation of Cape Cod. Stellwagen Bank has a minimum of 12 fathoms of water upon it, and not much more for its length of about 20 miles; then at the deep channel leading toward Boston Harbor the bottom suddenly declines to the depth of 60 fathoms. The evident suggestion is that Stellwagen Bank is a northward continuation of the Cape Cod divide and that Race Point channel marks the position of a col on the ridge, which was some 70 feet lower than the general surface of the water shed; and also that the Cape Cod Bay River joined what we may call the Boston River near the northern end of the above-named bank.

North of the valley of Boston River another less distinct, unnamed shoal continues the line of Stellwagen Bank in such manner as to suggest that a stream corresponding in a way to that of Cape Cod Bay headed about Cape Ann and flowed southward, joining the Boston River near where that passing from the Cape Cod divides entered it, the united streams flowing on through the Stellwagen ridge to the sea. The general likeness of the outlines of these antithetic valleys, if we may use that name to designate basins of very like character whose streams flow against each other, suggests that they are carved in like materials, or, in other words, that the Cretaceous and Tertiary strata of the Cape Cod district are continued as far north at least as Cape Ann, though they do not appear above the surface. This proposition is made the more probable by the discovery by Mr. Warren Upham of fossils of possible Eocene or Cretaceous age in the drift materials near Highland light. As such remains have not been found elsewhere in the drift of the cape, they have probably been brought from beneath the level of the sea.

Evidences derived from soundings and dredgings in the Bay of Maine indicate, as is well known, the existence of Tertiary and perhaps Cretaceous rocks, at least about the Grand Banks and Georges

Bank.[1] These and other observations indicate that the shoals to the east and north of Cape Cod are probably the remains of ancient divides, and the soundings warrant, in a measure, the interpretation of ancient river valleys, but this task will not here be further essayed.

ORIGIN OF THE CAPE DISTRICT PLATEAU.

An inspection of the contour maps will show that the pre Glacial beds of the cape district, including the islands on the south, have their upper surfaces everywhere at about the same altitude, with a prevailing slope from the western part of Marthas Vineyard, where they rise to about 300 feet above the sea, toward the east and north, declining at Boston Harbor to the sea level, near the end of Cape Cod to a little above that level, and at Nantucket to a height of about 50 feet. The question arises as to the origin of this approximately plane surface. It may be due to either of two actions—to base-leveling or to the leveling action of the sea—or possibly to a complex of these actions. It clearly is inadmissible to suppose that the plateaulike surface is due to the survival of the original stratification surface, for, as has often been noted, the area has been greatly disturbed. Against the supposition that the approximation to horizontality just before the uplift which set at work the streams that cut the valleys of the old rivers of this district was due to base leveling, we may note that this would require us to suppose a very long period in which these much-dislocated rocks had been slowly brought to a level by atmospheric agents. As we see at present on Marthas Vineyard these rocks yield but little to such action. The streams of to-day carry away scarcely any mud; their effect is limited to a slight leaching action. To introduce such a base-leveling period of sufficient duration would call for greater lengthening of the first Pliocene time than it is reasonable to make.

The leveling of this district by the action of the sea might have been accomplished in a relatively short time. The present rate of retreat of the southern shore of Marthas Vineyard is, as before noted, about 3 feet per year; at this rate the sea would occupy 2,000 years in wearing a mile into the land. The width of this table-land, including the submerged portion, being assumed at 50 miles, the leveling process would have required about 100,000 years. Great as this time is, it is probably much less than would have been required to effect the same result by the base-leveling process alone. Here, as elsewhere along coast lines, it is likely that these two actions cooperated, the streams carrying away what they were enabled to and the waves removing the portion of the material which was not thus taken to the sea. It is not likely, however, that the time occupied in the work could have been much less than that above suggested. Here, again, we

[1] A. E. Verrill, Occurrence of fossiliferous Tertiary rocks on the Grand Bank and Georges Bank: Am. Jour. Sci., third series, Vol. XVI, p. 323.

encounter the perplexing difficulty that the history of the beds of the successive epochs in this area requires us to suppose a lapse of time since the close of the Tertiary period much greater than is commonly assumed to have occurred.

POSITION AND CHARACTER OF DIVIDES.

The position of the several divides which mark the limits of the ancient partly drowned valleys of the Cape Cod district is such as would be expected in case the topography of the region had been developed when the surface of the country was at least 200 feet higher than it is at present. The most continuous of these crests is that of the cape itself, extending from the town of Plymouth eastward to Chatham and thence northward to the sand spit which terminates the cape. This divide may have been continued somewhat farther to the east, as will be noted hereafter. The arrangement of the valleys of the headwater streams in this section suggests their former union in two or more valleys, which declined to the north and south. North of the elbow of the cape to the Provincetown sand spit the incutting of the sea appears to have destroyed the original crest of the divide, leaving only the slope of the ridge which drained into the Cape Cod Bay river.

The divide which separates the water of the last-named stream from the upper tributaries of the Buzzards Bay river is still traceable in the long ridge which stretches in an interrupted manner from Monument River to the neighborhood of Plymouth Harbor, terminating in Manomet Hill. It is, indeed, impossible to account for the very peculiar shape of the ground in this district without supposing that it is due to the interlacing of the headwaters of adjacent but oppositely flowing streams. This western divide of the Buzzards Bay valley is continued southward in the united ridge on which the Falmouth moraine lies as far south as Woods Hole. From the harbor of Woods Hole the same divide is shown in a less united form by the line of the Elizabeth Islands to and including the island of Cuttyhunk.

On the south of Vineyard Sound we have in Marthas Vineyard the remains of the other crest of the valley of which the Elizabeth Islands form the other divide. This crest constitutes the northern range of hills of Marthas Vineyard, extending as far east as Vineyard Haven. The central and southern parts of the highlands of the island are on the headwaters of streams which seem originally to have flowed into the Muskeget River valley.

The island of Nantucket appears to be the remnant of several obscure divides, but the greater part of what is left above water is on the slope of the drainage toward the Muskeget and the Monomoy rivers. As will readily be seen, the directions of the ancient rivers in this portion of the district are by no means clear. This obscurity is mainly due to the extensive erosion by tidal currents which has taken place in this part of the field.

It is to be noted that the decline in the altitude of the principal divide of this district, that which extends from Plymouth Harbor to the extremity of the Elizabeth Islands—a distance of about 45 miles—is relatively steep, being from a height of about 300 feet to that of about 100 feet above the sea, or an average of about 5 feet per mile. In view of the considerable width of the valleys in this region, this decline must be regarded as greater than is consistent with the supposition that the region is anywhere near to being completely base-leveled. There is no definite evidence as to the rate of fall of these drowned valleys, but in valleys of such width, cut in materials of so yielding a nature, it is difficult to believe that it could have exceeded 5 feet to the mile. In considering this question it should be noted that the decline of the crest line is not necessarily a true measure of the fall of the valley. In general, however, this decline is, at least in the upper part of the river's course, much less rapid than the fall of the stream. Taking the remnants of the valleys as we find them in Marthas Vineyard, we note that they support the proposition that the bottoms of the old valleys had a slope less than is indicated by their present altitudes. The valleys of the Tisbury and Tiastquan rivers below the points where they are occupied by permanent streams have a fall of about 15 feet in a mile, yet these are the upper and presumably steepest portions of the river systems to which they belong. Although there are no very certain conclusions to be drawn from this inquiry into the slopes of the old rivers of the Cape Cod district, the fact suggests that there may have been some warping movements since the topography was formed.

It is to be observed that the three best defined of the old valleys of this area, those of Cape Cod Bay, Buzzards Bay, and Vineyard Sound, show a certain measure of narrowing toward their lower parts. This feature is most evident in the case of Buzzards Bay, but it is noticeable also in the other basins. This apparently indicates stream erosion working toward the formation of circus-shaped valleys, features which are not uncommonly found in much eroded areas.

In connection with the old valleys of this area the island of No-man's-land offers matter for interesting inquiry. This bit of land, by its position and its relation to the form of the sea bottom, suggests that it is the remnant of the southern divide of a valley the stream of which drained into Vineyard Sound river near Gay Head. The shoal about this island, though it is evidently subjected to much erosion by the strong current and waves, indicates that the isle, which is rapidly wearing away, was originally of much greater extent than at present. The retreat of its shores, which appears to be going on at the rate of about 3 feet per annum, will bring about its destruction in less than a thousand years. Its place will then be for a time occupied by a shoal which, under the cutting action of the waves and tidal currents, will be planed down to a considerable depth, coming finally to the state of the shoals in Nantucket Sound.

TRESPASSING OF RIVERS.

The position of the several divides between the ancient basins of the Cape Cod district indicates that the streams had advanced far in the development of their topography before the last great subsidence. Here and there we find evidence that the crests had been brought to rather sharp edges, having in most cases lost all trace of the original table-land character which seems to have been in some way impressed on them before the last invasion of the valleys took place. The Cape Cod crest was evidently sharp; so, too, was that of the Elizabeth Isles. That of Marthas Vineyard was of a more complicated nature, retaining much of the original table-land form.

The process of stream capture, of which there are good instances on Marthas Vineyard, which evidently took place before the last great downsinking that brought about the formation of the bays and sounds, shows that the adjustment of the topography about the heads of the streams on that island had not been anywhere near completely effected. Similar though less evident indications of such action on the mainland may be found in the valleys of Monument, Bass, and Pamet rivers, where streams had evidently in good part or altogether cut back through the divides, more or less invading the drainage of the antithetic stream. In two of the last-mentioned instances, Monument and Bass rivers, the transgression seems to have been made by streams flowing southward toward the valleys of the Nantucket Sound area. In that of Pamet River the slope seems to have been to the westward into Cape Cod Bay. The passages between the Elizabeth Isles were apparently much as we now find them before the close of the time preceding the last deep submergence. If this be the case, the head streams of either the Buzzards Bay or the Vineyard Sound river may have crossed the divides, and as these passages have been much changed by glacial action and by tidal currents it is not easy to determine in which direction the trespassing waters flowed.

As the valleys now occupied by the bays were evidently rather deep, probably at least 500 feet at their deepest part, below the higher parts of the divides, the incomplete nature of the topography on and near the crests is no good reason for supposing that their bottoms were much indented. It is a very common feature of river valleys to have their lower parts level and their upper parts deeply indented. We thus are not compelled to suppose that a great deal of filling has been necessary in order to bring about the general approximation to horizontality exhibited in the bottoms of the bays.

AMOUNT OF SEDIMENTATION SINCE THE PRESENT LEVEL WAS ESTABLISHED.

As noted under the last heading, the fact that the bottoms of the Cape Cod system of bays and sounds are approximately level can not be taken as evidence of any great amount of sedimentation since the sea attained to about its present position at the end of the last important down-sinking. A close study of the form of these bottoms, based on the soundings of the United States Coast Survey charts, shows a multitude of slight irregularities which can not well be attributed to the differential deposition of sediments due to tidal currents, but can best be explained by supposing that the layer of imposed detritus is not yet thick enough to completely mask the preexisting ridges and valleys of these submerged areas.

If there had been a great amount of deposition on the sea floor in the Cape Cod bays we should expect to find all the original irregularities of surface due to their erosion quite effaced, in the manner in which it appears to have been destroyed on the great southern plain or on a lesser scale on the morainal plain of Marthas Vineyard; but while there are traces of such depositional shelves near the shore, as on the southern coast of the last-named isle and along the south and east shores of Cape Cod, these shelves are narrow and flat. In form they evidently are quite unlike the bottoms of the water areas at a distance of 2 or 3 miles from the coast line. The evidence from soundings goes to show that the migrations of sand in these areas are locally considerable, but they appear to occur only in the paths of relatively strong tidal currents, such as sweep through the sounds and in the bays; it is to the effect that, notwithstanding all the coastal erosion which is going on, the contribution of sands to the bottoms of the bays at the distance of a mile or more from the shores is very slight in amount. These facts lead me to doubt whether as much as an average of 50 feet in depth of detritus has been accumulated on the floors of the bays since they last came below the level of the sea.

On the south side of Marthas Vineyard and of Nantucket and on the east side of Cape Cod the considerable invasion of the land by the sea has doubtless done much to contribute material for sedimentation, but in Cape Cod Bay and Buzzards Bay the erosion of the shores has not been sufficient to supply more than a few feet of detritus over the floors of the basins. The waste of organic life deposited in these basins is relatively small in amount, being much less than in those parts of the shores and shallows to the northward, where mollusks and seaweeds are more abundant.

Owing to the situation of the Cape Cod salient it is not in a position to receive detrital materials from a distance in the manner in which they are accumulated along the shore south of New York. North of the cape the deep trough passing outward from Boston Harbor inter-

cepts the current and wave driven waste coming from the northern shore. On the southwest there is no set of currents driving such material toward the waters of the sounds and bays. Some contribution may have been had from the wreckage of islands now reduced to shoals, but it probably has not been in large amount.

DEPTH BENEATH SEA LEVEL AND NATURE OF THE CRYSTALLINE ROCKS IN THE CAPE COD DISTRICT.

At no point in the district of Cape Cod are the ancient crystalline rocks exposed to view, nor does the drift covering on any part of the land indicate by its character that these deposits are on the land areas, at least near the surface. In passing from the mainland toward the cape we find the nearest localities of the crystalline rocks at Plymouth Harbor and on the west shore of Buzzards Bay. Throughout the southeastern section of Massachusetts these rocks exhibit a gentle and tolerably uniform slope toward the base of the cape at the rate of about 20 feet to the mile. This would place the old granite series at the level of 100 or 200 feet below the sea level on the eastern shore of Buzzards Bay and at a depth below that plane of about 1,000 feet at Chatham Harbor. Inasmuch, however, as all this region has been greatly disturbed, and as the disturbances most probably included extensive movements of the ancient rocks as well as of the Mesozoic and Cenozoic strata which rest upon them, no great value can be given to these estimates.

On Marthas Vineyard and scantily on the shores of the southwestern portion of Cape Cod, particularly along the southeastern side of Vineyard Sound, as before remarked in the account of the glacial drift, a great quantity of chalcedonic quartz pebbles are found. So abundant are these coarse agates that hundreds of tons of the material could at times be gathered along the shore. It is evident that these fragments have been glacially transported, and, as is indicated by the character of the layer of erratics as well as by the glacial scratches, the movement of the ice was from the northwest, if indeed it was not from a point nearer the west. Nowhere on the mainland are rocks of this nature known either in situ or in the drift. Along with these chalcedonic erratics go great quantities of pebbles of white-vein quartz of an aspect quite different from any known on the shores to the northward. A close comparison of the pebbly materials on the islands of the Cape Cod district with the rocks on the mainland will undoubtedly show other cases of this kind. On the body of Cape Cod, in increasing proportion as we go from Monument River eastward, we find groups of vein and volcanic materials differing in nature from those on the neighboring islands. In this last-mentioned district the pebbles of volcanic rocks are very abundant, especially in and beyond Orleans.

The evidence afforded by the erratic materials of this district shows

that just to the seaward of the shore line there is both to the north and the south of Cape Cod a belt of rocks which have been the seat of great volcanic and solfataric action, and that these deposits have been much metamorphosed. In this connection it may be noted that a belt of disturbance of the nature indicated on the sea bottom about Cape Cod begins in the region about the Bay of Fundy and extends parallel to and partly within the shore along the coast of Maine. I have noted the occurrence of such conditions in the published accounts of work done for the Survey in the districts about Passamaquoddy, Cobscook, and Orange bays, and in the district of Mount Desert and on Cape Ann. In the two first-named fields the presence of distinctly volcanic deposits is well proved. At Cape Ann evidence of true volcanic action is lacking, but the extraordinary amount of dike injections, which evidently increases as the shore is approached, shows the effect of the same system of disturbances. It thus appears probable that the coast line of this continent, from the head of the Bay of Fundy at least as far to the southward as the mouth of Buzzards Bay, lies upon the inner margin of a tract which has been greatly subjected to volcanic and solfataric action. It is not improbable that the indentation of the first-named bay may be due to the subsidences connected with these disturbances and that the position of the coast line on this part of the shoreland is to be accounted for either by the downward movement or by the relative ease with which the coastal fringe of rather incoherent deposits were eroded by the sea. Interesting as these questions are, they can not be followed further here except to suggest that the volcanic areas of the Boston Basin, of the Connecticut Valley area, and of the region in and near the lower part of the Hudson Valley, where there is reason to suspect that the volcanic rocks are newer than the Newark beds, are within the limits of this marginal fringe of such deposits.

FOSSILS DREDGED FROM SEA FLOOR NEAR CAPE COD.

From time to time there have been reports that fossils of a character which would indicate that they came from beds such as are found on Marthas Vineyard or at Marshfield existed on the sea floor to the north and east of the cape. These specimens have been brought up on anchors or by the dredge. It seems likely that in all these instances the materials have been derived from the drift deposits on the floor of the sea, though it may be possible that, as about Georges Bank, the considerable energy of the tidal currents may scour away the soft parts of the bottom, leaving the harder fragments as a coating on the sea floor.

The evidence above referred to, though fragmentary, and at best not very trustworthy, is enough to show that to a considerable depth, say to 200 feet or more, the bottom is, in part at least, occupied by the fossiliferous deposits which were here and there exposed in the cape district just before the Glacial period. This serves to show that the

erosion which took away so large a share of the later pre-Glacial accumulations—those designated as the Truro and Weyquosque series or the Barnstable clays—affected a large extent of the sea bottom for a considerable distance out to sea. Without attaching too much importance to this obscure evidence, it may well be taken as of some value in showing that the region was for a long time elevated to the height of 200 feet or more above its present level, or, what comes effectively to the same thing, that the sea was at about that depth below its present plane. Thus the considerations going to show a recent submergence, which are derived from the topography of the coast and the drowned valleys, has some support from the evidence which these chance samples of the bottom afford.

It has been suggested that these fossils brought up by dredging may be from the drift deposits which are presumed to exist for some distance to the east beyond the shore. Against this hypothesis may be set the fact that fossils of the Cretaceous and Tertiary beds have rarely been found preserved in any glacial deposits, even where those beds lay immediately upon the strata richest in organic remains. The probability that they would thus occur in quantities sufficient to account for the numerous chance finds is so small that it may be disregarded.

TIME RATIOS INDICATED BY POST-TERTIARY PRE-GLACIAL EROSION.

It is not possible, in the present state of our knowledge, to undertake any final essay in determining the time occupied in the erosive work done in this region since the close of the Pliocene epoch. It is, however, possible to give some general and relative indication of these durations.

The facts show that after the deposition of the Pliocene deposits of Marthas Vineyard a vast erosion occurred, which shaped the strong topography that is exhibited in the western part of that island. In the present condition of that area, though the valleys are deep and much of the surface is but slightly drift covered, the rate of stream erosion is almost nil. Even in times of heavy rain the brooks show hardly a trace of color due to other than the stain of decayed vegetation. In the period before the deposition of the drift the rate of wear was probably more rapid than it is at present, but it is impossible to estimate the value of this difference. We are therefore left to mere impressions as to the time required for the development of this topography. These inferences, however, are of some importance.

It is in the first place to be noted that the rocks of this region are, and have been from the time of their formation, very open-textured. They readily absorb the rain water, which cuts no channels on these areas, which are so nearly driftless that the Cretaceous and Tertiary deposits are essentially at the surface. This must have made this field, with any rainfall, which was not very much greater than that of to-day,

one of slow erosion, for the reason that the waters entering the ground would have been discharged, as they now are, at the level of the permanent streams and in a very gradual manner. This action may now be seen in fields of great extent, as in the town of Chilmark, or near Gay Head. Nor can we suppose that the water penetrating to the depths exercises any considerable solvent action. The strata which it traverses contain very little soluble matter, and the springs—save that they sometimes exhibit the results of decomposing pyrites in the sulphureted hydrogen they give off and contain a considerable amount of alumina sulphate—are essentially pure. The facts above noted lead to the conclusion that the erosion of the Vineyard area has from the beginning been slow.

On the basis of a slow erosion we have to account for the formation of river valleys a mile in width and having a depth of from 150 to 200 feet, as well as for the renewal of an unknown section which has been worn away from the crests of the hills. Assuming that the average ablation of the area has been at the rate of 1 foot in one thousand years, a rate which must be accounted rapid—it is equaled, so far as ascertained, in no part of the world which bears a covering of natural vegetation—in that it would at this rate of cutting require somewhere near 200,000 years to carve out these valleys; but, as is easily seen, the valleys are only a part of the result of the erosion which the streams have applied to them. The elevated country between these troughs has also gone down, so that it does not seem unreasonable to assume that the total erosion of this valley-making period has required 300,000 years.

Beyond the clear evidence of a long erosion interval afforded by the valleys of Marthas Vineyard we perceive that there is an unmeasured and perhaps immeasurable time which intervened between the period when the rocks in which the depressions exist were dislocated and that when valley-making began. It seems tolerably evident that in this period the sea stood some hundred feet higher than it does at present and that the surface was gradually base-leveled until it came nearly to the plane indicated by the highest land of the island. This little-indicated period of erosion, the sole evidence of which is found in the faint yet distinct marks of an ancient plain, antedating the formation of the present drainage system, possibly represents a duration several times as great as that shown by the action of the streams which now are at work.

In a general way following the development of the valleys of Marthas Vineyard and those which were formed in the tilted deposits of Cape Cod, came a period of deposition in which the various beds of Nashaquitsa, Barnstable, and Truro series were laid down. The history of this stage or stages in the development of the cape district is not yet unraveled. These several sections may all be of the same age or they may represent, to a greater or less extent, the history of

successive periods. However this may be, there can be no doubt that the time occupied in the deposition of these beds was very great, and that the detritus which was accumulated came in part, if not altogether, from areas north and west of the cape district, as is shown by the fact that the beds in question to a great extent mantle over the ancient topography and rise to near the level of its highest elevations.

Following the accumulations of the Truro-Barnstable groups came the third great period of aerial erosion in this field. During a period of elevation which brought the land to a level at least 200 feet higher than it is at present, the erosive work of the streams cleared away the deposits of stratified sands, clays, and gravels from the valleys which it encumbered, and extended the denudation of those broad and thick sheets of strata until only remnants of the original mass remained. The amount of erosion effected during this period immediately antedating the last ice epoch can not be gauged, for the reason that the greater part of the area in which it was effected is now submerged beneath the sea; but it was clearly much greater than that which was done in the time to which we owe the development of the several valleys of Marthas Vineyard or the like troughs of Cape Cod. To it we owe not only the general clearing out of those troughs, but the excavation of the river basins which are now marked by the bays and sounds of southeastern Massachusetts.

In considering the time required for the formation of the later stratified deposits of the Cape Cod district we have first to note that the accumulation of these beds indicates a long period of erosion, the record of which, as before remarked, is not found in this area for the reason that it was then beneath the sea. As the work done was of sufficient magnitude to form a broad sheet of detritus, extending from some point far inland, probably the central highlands of Massachusetts, to and beyond Truro and Nantucket, having a thickness on the average of not less than 100 feet, and perhaps several times as great, it is evident that the time occupied could not well have been less than that attained for the second erosive period—that which shaped the greater valleys of Marthas Vineyard. The last great erosion period—that which morcellated the stratified deposits which overlapped the old mountain-built beds—appears to have required more time than any of the earlier periods of wearing. The valleys were brought to a great width. Nearly all the deposits of the last formations were removed, leaving only fragments of them on or near the divides. As this work was done mainly on very permeable beds, into which the rain penetrates rapidly without developing small, superficial streams, the work of wearing could not have proceeded with great rapidity.

The facts as above presented lead to the conclusion that since the close of the Tertiary period, or perhaps from some time after the end of the Pliocene epoch and down to the advent of the ice in the last Glacial epoch, there have been four tolerably distinguishable periods of erosion

in this field, each requiring a time the duration of which, even in a geological sense, must be accounted as long. Various estimates, made on the basis of the present rates of erosion, lead me to the conclusion that this interval was not less than one million years.

Without attaching any definite value to the reckonings as to the durations of the periods in which the wearing down on this district was effected, it may be claimed that no geologist who has attentively considered the problems of time ratios in erosion is likely, on a careful study of this field, very much to reduce this estimate. Although the assumption of something like a million years for the interval between the end of the Tertiary and the beginning of the last ice epoch is not in accordance with the views as to the time ratios in the later stages of geological history which were entertained down to the beginning of this decade, it is becoming evident that the old view as to the brevity of this interval was hastily taken and will have to be revised. It is in order to bring this point into debate that the previous estimates as to the time occupied by the completed succession of actions which have taken place in post-Tertiary pre-Glacial time are here submitted.

It may be remarked that the prejudice in favor of a brief time since the close of the Tertiary period has rested in part on the fact that the amount of consolidation which has taken place in the deposits of that portion of the earth's history has been in most cases small. It is, indeed, difficult to believe that beds which have been as little changed as the strata of this age usually are have been formed for millions of years. When, however, we note that in Mesozoic rocks, and even in those of the Paleozoic sections, the amount of alteration is often slight, we can well understand that these more recent deposits, which have not undergone deep burial, have survived for ages without essential change.

SUMMARY AND CONCLUSIONS.

The results of the observations noted in the preceding pages of this report justify the following statements relating to the Cape Cod district, and particularly concerning the peninsula of that name.

After the erosion of the Cretaceous and Tertiary beds disclosed on Marthas Vineyard, several series of sedimentary deposits were laid down. The first of these deposits, which may fairly be reckoned as of early Pleistocene age, though deposited in horizontal attitudes on the disturbed older beds, were in turn somewhat stressed, the resulting dislocations being relatively much less considerable than those which affected the Cretaceous and Tertiary deposits. These dislocations are evident not only on Marthas Vineyard but throughout the area of Cape Cod between Woods Hole, Bourne, and Highland Light. They also extend up the coast at least as far as Plymouth Harbor; their western extension is not yet determined.

The post-Tertiary deposits just referred to appear to be divisible into two groups, the lower of which is exhibited on Marthas Vineyard and

in Cape Cod as far north as Monument River and eastward to Orleans. This series is characterized by the presence of red clays and sands, which appear to owe their origin to the decomposition of Tertiary strata such as occur at Gay Head. Apparently above these beds, which have been termed the Nashaquitsa series, occurs another series, here known as the Truro. The characteristic of these beds is that they plentifully contain a fine, white, floury, micaceous sand, which is very much decayed. These sands are combined with coarser arenaceous materials and occasionally clay beds, the clay being of the ordinary grayish or yellowish hue. So far as is ascertained, these beds contain no pebbles of compound rocks, the pebbles, indeed, being very rare and, so far as observed, of quartz, and always small. The Truro series has not disclosed any materials apparently rising from decomposition of the Tertiary beds. It is possible, but not probable, that the Nashaquitsa and Truro series should be regarded as one group. The distribution of the beds, however, is against this view.

The group of brick clays known as the Barnstable series appears to have been laid down after the Nashaquitsa and before the Truro beds had been formed and dislocated. The evidence as to this succession, however, is not perfectly clear.

During the deposition and erosion of the series above noted the Cape Cod district has been subjected to a number of movements of elevation and subsidence of which the imperfectly interpretable changes are shown in fig. 87, p. 522. These movements indicate very remarkable instability in the position of this portion of the continent from Jurassic time to the present day, but the alterations of level appear to have been limited, so far as determinable, to a range not exceeding, perhaps, 1,000 feet. It is to be noted that these accidents appear to increase in frequency as we approach the present day. This, however, is most likely due to the fact that the records are more complete and interpretable as they come toward the present time; possibly, also, as my colleague, Mr. J. B. Woodworth, has noted to me, for the reason that the later records are more coastal in their nature than are those afforded by the earlier deposits. It is to be remarked as a very significant feature that the series of deposits from and including the Nashaquitsa to the close of the Barnstable series have afforded no fossils. It is possible, but not probable, that fossils may have been contained in these beds, the remains having disappeared under the very free leaching which has occurred throughout this area, where the rocks are extraordinarily porous.

It is possible, and perhaps probable, that these beds, in part at least, represent deposits in advance of glacial sheets. Nevertheless, as we have to suppose that in part the materials were laid down in salt water, it is not easy to understand the complete absence of organic remains, which, as we know from other fields, even those near by, as on Nantucket and on the coast of Maine, contain abundant fossils. Moreover,

it is difficult to believe that during the extended topographic changes which occurred while the three series above mentioned were depositing, and also during the period of dislocation, which is marked in the attitude of the beds, no ice could have remained near enough to the district to affect the character of the sediments. Still further, the absence of erratic rocks in the Nashaquitsa and Truro contraindicates the action of ice.

The condition of the deposits contained in the series of the Cape Cod district, formed after the close of the Tertiary and before the advent of the glacial sheet, indicates the rapid erosion of an area of crystalline rocks which had previously been affected by a deep decay. It is conceivable that this erosion, acting on softened materials, was due to rivers, but the general absence of vegetable matter in the deposits makes it perhaps more likely that the work was accomplished by glacial erosion occurring during the periods of subsidence which are indicated by the sections.

The facts stated in the preceding pages of this report make it clear that the post-Tertiary and pre-Glacial history of southeastern Massachusetts is much more complicated than has hitherto been supposed. The interpretation of the record which has been given must be regarded as in a great measure tentative. A further development of our understanding of the facts will doubtless be attained when the related deposits on Long Island, New York, have been explored. There is reason to hope that in that field may be found the passage from the conditions of southeastern New England to those accepted in the related Columbian beds and other recent deposits in New Jersey and the portions of the coast to the southward.